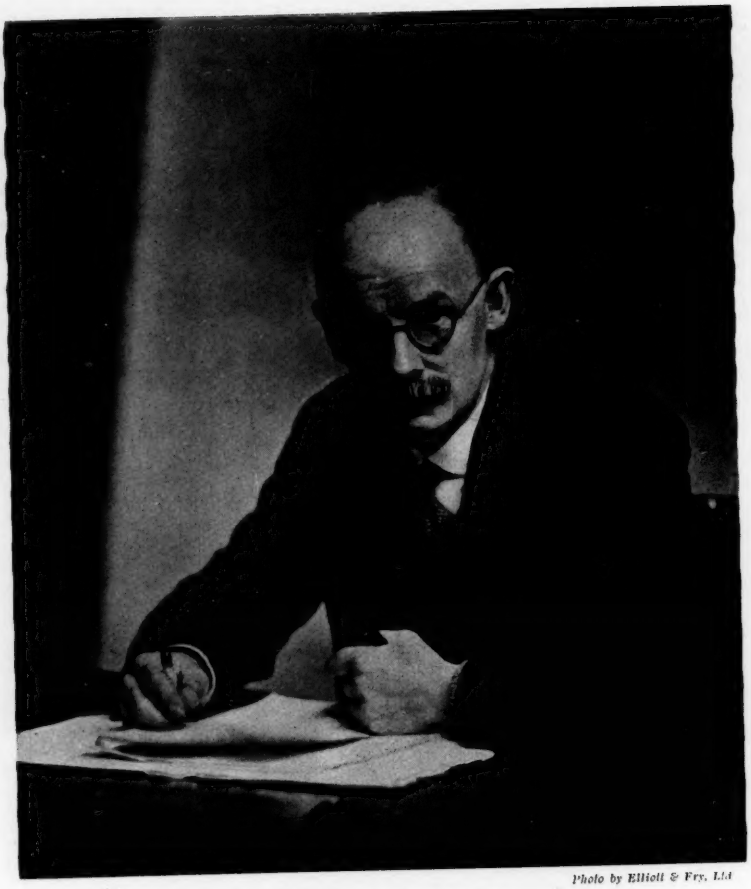

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ROBERT RUTSON JAMES

Medical
Faxon

THE BRITISH JOURNAL

OF

OPHTHALMOLOGY

JANUARY, 1949

COMMUNICATIONS

TEMPORA MUTANTUR

A NATIONAL scientific journal has many parts to play. Its main duty, of course, is the recording of advances in the subject it professes, and the provision of a means whereby new ideas developed in the country of its origin can be passed into the general circulation of world thought; it should also offer the hospitality of its pages to those workers in other countries who have something to contribute to the general store of knowledge so that the practice of one country can be enriched by the progress of another. But a function of little less importance is to interpret the national spirit so far as the specialty with which it deals is concerned—for each people has its own peculiar means of expression—to nurse this spirit by inspiring its own nationals and to impress it, for what it is worth, on the corporate body of international thought. Moreover, it should foster the desire for enquiry and original observation in its own country and, as a common link and means of expression, bind together the members of the profession into a community with common interests and aspirations.

In these respects the British Journal of Ophthalmology has indeed been fortunate hitherto in those who have guided its policy. Ever since it was founded thirty-two years ago Sir John Herbert Parsons has been the Chairman of its Editorial Committee and our regrets will be shared by all our readers in many lands beyond our shores that he has now vacated his chair. No matter who guides its policy, however, if it is to have any merit and if it is to fulfil its responsibilities, a journal must lean heavily on its editor. To some extent, of course, he is limited by the material presented to him, but the impress of his personality must have a profound influence on the spirit of the publication. For 25 years this Journal has been fortunate in having the services of Robert Rutson James on its Editorial Committee, and for the last 19 years he has occupied the editorial chair. One of the most erudite, and at the same time lovable members of our profession, he has successfully maintained the traditions of the British Journal of Ophthalmology, guiding and encouraging our contributors and impressing his humanity and his unusual geniality upon our pages. Throughout his long tenure of office, he has never spared himself but has laboured faithfully in carrying out his onerous editorial duties, obviously loving everything he has done. It is with regret that we wish these two, who have carried the main responsibility of this Journal for so long, an official farewell; but we who carry their mantle are inspired by their example and comforted in the thought that neither has left us, for we hope they will long be with us to give us help and encouragement.

For the last 19 years Hyla B. Stallard has acted as Assistant Editor of the Journal and has been largely responsible for the technical supervision of its publication. Anyone who is acquainted with the intricacies of periodical publications will understand how fortunate we have been in having the services of one at the same time so able, conscientious and meticulous in everything he undertakes; and everyone who knows him will share our pleasure that he remains upon the Editorial Committee to serve the interests of the Journal in the future.

With the commencement of the thirty-third volume the Editorial Committee has been reconstituted and the Journal finds a new home in the Institute of Ophthalmology in London. Fortunately the new Committee retains most of the members of its predecessor; it thus has the advantage of continuity in maintaining a tradition of which it is proud.

THE RUPTURE OF THE ZONULE IN INTRACAPSULAR CATARACT EXTRACTION—A NEW METHOD*†

BY

DANIEL B. KIRBY

NEW YORK

THE rupture of the zonule (zonula Zinnii) of the crystalline lens is the *sine qua non* of intracapsular cataract extraction. It is the purpose of this paper to record some personal observations and experiences and to add them to existing knowledge of the best means of rupturing the zonule in various types of eyes with their different cataracts and zonules. The finding of a fairly large percentage of resistant zonules in the author's surgical experience is accounted for by the fact that the greater proportion of the cataracts operated upon are in the immature stage. In this period, both the capsule and the zonule are more nearly normal and resistant than in mature or hypermature cataracts when both capsule and zonule may be quite fragile. The author's system of intracapsular cataract surgery will be further explained and his new method for direct rupture of the zonule in difficult cases by stripping it from its attachment to the lens capsule will be elaborated upon.

Applied surgical anatomy. The zonule.—The zonule may be defined as the suspensory ligament of the crystalline lens. It consists of homogeneous glass-like fibres covered by a delicate lamella on their anterior surface, taking their origins from the ciliary body, and from the ora serrata where their arrangement undoubtedly accounts for its serrated appearance. The principal fibres run in the ciliary valley and by their early presence and strong formation account for the alternation of ciliary processes and valleys. Termination and insertion is made by the fibres splitting and diverging to fuse with the zonular or most superficial portion of the anterior lens capsule and with the capsule itself in its equatorial portion. In the living, normal eye with the zonule surrounded by aqueous, the lamella being of the same index of refraction as the aqueous, is invisible even with the magnifications possible with the slit-lamp microscope. Only when the eye is opened as in surgery or in the dissection of the fresh specimen is the lamella visible when exposed to the air, and then only when properly illuminated, best with parallel rays of incident light and

* An abstract of this paper was read before the Pan-American Association of Ophthalmology, January 6, 1948.

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viewed with magnification of two or more times. The descriptions of the older anatomists who examined fresh specimens and others who have recently done likewise, rather than those who come to depend upon fixed material, correspond with my clinical surgical observations. The processes of fixation, dehydration, imbedding, sectioning and staining cause the disappearance of the delicate zonular lamella.

The ligamentum hyaloidea capsulare.—Clinically, in intracapsular surgery the ligamentum hyaloidea capsulare does not seem to be more than a coaptation of the hyaloid to the posterior lens capsule, the easiest manoeuvres releasing it. Only in the rare or exceptional case are the hyaloid and the vitreous apparently really adherent to the posterior lens capsule being drawn up in cone shape when the lens is lifted vertically. In the average case, the ligamentum hyaloidea capsulare is easily separated by the manoeuvres directed at the rupture of the zonule and no particular attention need be directed to the former.

Embryology.—The origin of the zonular fibres, at least in the chick embryo, I believe, is in the prolongation of the protoplasmic adhesions which develop when the primary optic vesicle touches the surface ectoderm to stimulate the formation of the lens. After the development of the secondary optic vesicle, the fibres suspend the lens vesicle from the rim of the optic cup. As the ciliary body and iris grow forward from the rim, the fibres are further stretched out and finally in the adult reach between the ora serrata, the ciliary body and the equatorial portion of the lens capsule. The zonular lamella is most probably laid on at the time of the formation of the tertiary vitreous. It is a fallacy that the lens primordium is cast loose into optic vesicle and cup, the zonule being formed later at the time of development of the tertiary vitreous. My observations of the protoplasmic adhesions and the presence of primordial zonular fibres even at the time of the earliest lens formation were made in the course of microdissection of living chick embryos at various ages for the determination of the best age at which the lens might be removed in capsule for pure cultures of lens epithelium *in vitro*.[1] Prior to the time of five days incubation there is not enough space between the pigmented tissues and the lens for separation without leaving pigment cells still attached to the capsule and after five days the zonular fibres become too strong for separation without tearing away pigmented cells or lens capsule. Observations on living embryonic specimens gave me a clearer idea of the origin of the zonule than the study of fixed, stained and cut embryonic material.

The place of the rupture of the zonule.—Observations of cataracts removed in capsule demonstrate that the break in the

zonule is at its union or fusion with the lens capsule. The fibres are the strongest and most important part of the zonule and apparently do not break in twain but separate with a portion of the zonular lamella at the capsule leaving the equatorial portion of the cataract smooth and free from any and all evidence of broken fibre remnants. These findings are contrary to the report of Goldsmith[2] and others, but have been described separately and confirmed by Berliner[3], and others. The clinical observation has also been made that in cases of traumatic subluxation of the lens, there are no microscopic bits or stubs of fibres of the zonule attached to the equator of the lens whereas in congenital subluxation, the defect or coloboma of the zonule is in the region of the ora serrata, the zonular fibres being visible in the area bared by the subluxation of the lens. The separation of the zonule at the capsule accounts for the lack of untoward reaction to surgery of eyes from which the lens has been properly removed in capsule. It also bears out my observation made previously that any pressure used to rupture the zonule should be point pressure or made in the narrow zone of attachment of the zonule to the capsule. Trauma, other than that of traction upon the ciliary body by the lesser zonular fibres, accounts for the development of cyclitis when it does occur after cataract surgery. The relatively low index of the complication of detachment or disinsertion of the retina after intracapsular surgery should calm the fears of those who believe that traction on fibres which took their origin at the zonule might produce separation of the retina.

Various manoeuvres for rupture of the zonule

The manoeuvres designed by various surgeons for rupture of the zonule in intra-capsular surgery are: I. Indirect Rupture by (*a*) Pressure from without, (*b*) Traction on the lens or its capsule and transmitted to the zonule, (*c*) Rotation of the lens in its capsule, (*d*) Various combinations of the above manoeuvres. II. Direct rupture of the zonule used alone or in combination with others of the various manoeuvres described above for indirect rupture to effect delivery by extraction or expression.

The rupture of the zonule is nearly always partial at first and is extended gradually through various forces until it is complete. The most important step in the rupture is the initial one. Some surgeons have one manoeuvre which they try to use in every case, making the eye adapt itself to the manoeuvre. For some eyes almost any manoeuvre is good and sufficient because the zonule is fragile. In case of failure either through inability to rupture the zonule or through rupture of the capsule or untoward immediate or later

effects in the eye itself, the blame is put upon the eye because of lack of adaptability. Rather should the surgeon have all of the above manoeuvres in his surgical armamentarium as his system for rupture of the zonule, and apply the one which is suitable to the particular case. All are valuable alone and in combination. Once started, a rupture may be extended by further procedure, the tear or dehiscence widening and enlarging from the starting point until the lens is freed.

Definitions.—By indirect rupture of the zonule is meant rupture by means of manoeuvres applied through an intermediary tissue, such as the cornea, sclera, lens capsule or vitreous, whereas *direct rupture of the zonule* refers to application of a manoeuvre directly to the zonule by a new method which has proved to be feasible and can be used safely and in a conservative manner under direct visual control when other manoeuvres fail.

The discussion of the various manoeuvres.—It will be well to consider each of the manoeuvres in order to evaluate them, to learn the limits of each in their application, to decide how to apply each to achieve the desired result with the least trauma to the eye, so that prompt graceful healing will supervene and long lasting excellent visual results obtained.

INDIRECT RUPTURE OF THE ZONULE

We will first consider the various manoeuvres producing *indirect rupture of the zonule* separately and together.

PRESSURE

Pressure may be applied directly to the lens or upon the outside of the eye. The ancient surgeons who couched lenses used pressure from within the eye after having pierced the cornea or more frequently the sclera. With a sharp instrument they impaled the lens or with a dull instrument they pressed against the lens forcing it back with the capsule broken or intact in the operation of depression or reclination. Apparently they found then as many resistant zonules as we do now, for when the latter were unyielding they often had to resort to the operation of opening the lens capsule and comminuting the cortex and nucleus, hoping for solution and absorption.

Smith[4] was the greatest exponent of pressure as a means of rupturing the zonule for intracapsular delivery. I believe much can be learned from Smith's work, even though we do not agree that pressure alone is good. Because of anatomical relations, I believe that pressure should be applied by a relatively pointed instrument, as for example the tip of a fine lens expressor hook on

the outside of the cornea. Smith was probably the first to use a strabismus hook for the purpose. I found the tip of the Smith hook too large to be insinuated between the equator of the lens and the ring of the corneal limbus. I have the same objection to other blunt or rounded expressors. I have adapted the hook of Jamison[5] for the purpose, and for ease of manipulation have put a 5 mm. cylindrical handle on it (Fig. 1). After making a superior limbus incision, I selected equidistant points below at 6, 8 and 4 o'clock on the corneal dial, just inside the ring of the limbus of the cornea, for the application of pressure. This semi-circular area is directly over the zonule where it joins the lower equator of the lens.

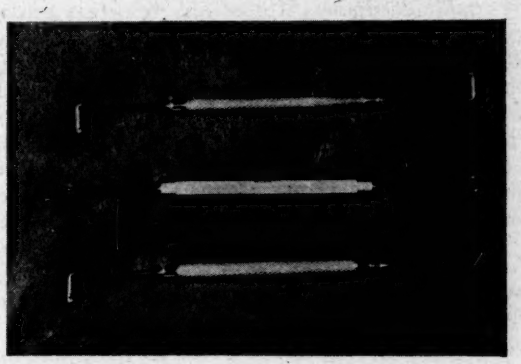

FIG. 1.

Half-size photograph of:—1. Kirby double-ended lens expressor hook. 2. Kirby lens expressor hook with lens loop at opposite end. 3. Kirby lens expressor hook with iris spatula at other end.

The point pressure I have used as an initial procedure before traction or rotation and have applied it in a fairly sudden and sharp fashion, indenting the cornea at the three points 2 to 3 mm., and causing the incision to gape diametrically opposite. Unless contra-indicated, these points may be pressed upon a second time. In some cases, it is evident that a fragile zonule has ruptured below. In such a case, if such pressure were continued, the lens could easily be delivered by expression alone, tumbling out, the hook being insinuated through the cornea back of the lens, following it up in its tumbling manoeuvre and, as it makes its exit, sweeping away the cataract by stripping off the remaining upper zonule in all effects the same as Smith described years ago. I have seen a good many cataracts subluxate below in the manner described following the initial pressure, but have had no desire to tumble

them out by pressure alone because it is so easy to pick them up with a suitable forceps[6] and lift them out because of the fragility of the zonules in such cases; and the principle of pressure alone for rupture of the lens in all cases is not a good one. I believe that pressure outside the limbus ring of the cornea is contra-indicated and ill-advised, unnecessary and inefficient, unduly traumatizing, and productive of complications both immediate and late. The use of blunt instruments for pressure is not good because they cover too wide an area, and do not reach the zonule and cause more trauma than necessary.

Point pressure.—The procedure of point pressure, as used by me[7], does not affect rupture of the zonule below in over 15 per cent. of the cases operated upon. It does not rupture the zonule in the average case or in those with resistant zonules. However, if not contra-indicated it gives valuable information, even though rupture of the zonule below is not effected. It reveals the thickness and resistance of the cornea and sclera, the intra-ocular tension or pressure after the incision has been made, the condition of the vitreous, the size and shape and consistency of the cataract and thus permits me, as the surgeon, to judge how best to proceed with the extraction of the cataract.

TRACTION

Traction may be applied prior to the manoeuvre of pressure as Knapp[8] first did with forceps, or it may be applied after or simultaneously within the pressure. I believe the latter most efficient[9]. The manoeuvre of traction may be applied (1) with a loop placed behind the lens, (2) with a pointed hook impaling the lens, (3) with the electro-coagulation electrode of La Carrère[10], (4) with the suction cup either of Dimitry[11] or Bell[12] or the erisphake of Barraquer[13], (5) with the aid of forceps grasping the anterior capsule of the lens.

Traction alone is not a good manoeuvre for rupturing the zonule unless it is applied to certain sections of the zonule at a time. The zonule as a whole is relatively strong and it stands to reason that the zonule as a whole is more resistant than any of its continuous parts. Non-traumatic cataract surgery must be based on a system of a small initial rupture of the zonule being made, this being extended until the whole zonule is ruptured and the lens made free for delivery.

1. *The loop.*—The use of traction by the loop may be indicated when the zonule is partially ruptured, when the loop may be passed through the area of the rupture. It does not seem advisable to use it routinely or to create the initial rupture in the zonule above the loop being passed through it according to the old technique of

Pagenstecher[14] even though he said he could pass it between the posterior capsule and the hyaloid without disturbing the vitreous. Once in place the loop behind the lens, in cases of subluxation, is a good instrument to support the lens and to withdraw it, provided the zonule is fragile, but not so when the zonule is resistant, then it is better judgment to use other manoeuvres as indicated. I have used the loop to bring the subluxated lens into position for use of forceps on the lens capsule and then have used the loop to strip off the portion of the zonule which is still adherent so that the lens may be freed for delivery. If viscid vitreous is anterior to the lens, then the loop is apparently the only safe instrument to use to get the lens into position for extraction. There is hardly any need for a barbed hook or vectis, based on the principle of the points engaging the lens for greater traction.

2. *The pointed hook.*—The pointed hook has been used by some to impale the lens and to draw it from the eye. Those who have done much capsulotomy surgery and have used the cystotome have undoubtedly all had the experience of the lens nucleus being fixed by the point and the zonule when fragile being ruptured and the cataract being withdrawn from the eye. The puncturing of the capsule in this manner will only give a small percentage of deliveries in capsule in the average case even though purposefully applied and it cannot be recommended.

3. *Electro-coagulation electrode.*—The electro-coagulation electrode of La Carrère has been used for changing the protein of the lens cortex and nucleus, causing it to adhere to the electrode and thus permitting the withdrawal of the lens in its capsule. This may be feasible if the zonule is weak, but the procedure can hardly be said to change or weaken the zonule unless it is carried to an unsafe and traumatizing degree. I have had no experience with it.

4. *The suction cup—erisiphake.*—The suction cup of Dimitry or Bell or the erisiphake of Barraquer would be excellent instruments for traction alone, if it were desirable to take up a relatively large portion of the capsule. This would be true if the zonule were always fragile or if it broke as a whole, instead of starting at a small area and then tearing gradually from this beginning. The suction cup is usually applied near the central area of the anterior lens capsule tenting up the entire capsule and zonule if lifted directly up. It is appreciated that in practice the manoeuvres of drawing the cup toward the surgeon as well as of turning the instrument to one side or to the other are feasible, but still the area of capsule affected is too large for easy rupture of the zonule. The instruments are relatively clumsy in their application, take up too much room and do not permit of the application of point pressure, or of rotation or of direct rupture of the zonule by stripping it off

the capsule as adjuvants in the removal of cataracts with resistant zonules. It is true that the suction cup can be applied to the tense or taut and rubbery capsule in certain cases of intumescent cataract when attempts to take up the capsule with forceps fail, but unless the zonule in such cases is found to be fragile, it might be better to release the grasp of the suction cup and to remove some of the fluid from the lens by aspiration as done by Traquair[15] or by point puncture as done by Riddell[16] and then proceed with forceps extraction in capsule. I have not had experience in doing this, but I have opened the capsule and proceeded with the capsulotomy extraction. In some cases where it is evident in the pre-operative examination that the capsule is taut, it has seemed best judgment to permit the cataract to go on to maturity, when it could be handled more gracefully. I appreciate the fact that Barraquer has had success that is admirable, but still the objections as detailed above have been learned in a practical way by others who have tried the use of the suction cup.

The technique of Barraquer includes the principle of traction through the medium of a relatively strong suction effect, which permits considerable direct traction effect with the application of the pressure below and at the side as well as torsional effect combined with pressure through the cornea on the zonule which is under tension, tumbling the lens from one side to the other. The lesser degrees of traction obtainable with the suction syringe of Dimitry or the pipette suction tip of Bell do not afford enough negative pressure to tumble the lens on its vertical axis. Fortunately, it is true that with lesser degrees of suction, the cup will come loose before too much traction is made upon a resistant zonule.

5. *Forceps.*—All surgeons who did capsulotomy extractions, including von Graefe, have most probably had the experience of having the lens coming away in capsule when using toothed capsule forceps designed to remove a segment of the anterior capsule. The teeth have penetrated the relatively thin capsule and have taken a sufficiently firm hold on the hard nucleus to effect with traction the rupture of a fragile zonule.

This happened frequently to Kalt[17], who used his relatively smooth bladed forceps for removal of a section of the capsule, so he purposefully tried to remove the average cataract in its capsule, succeeding in 25 per cent. of the cases. Knapp found no reason to change the model of the Kalt forceps for his intra-capsular cataract surgery and succeeded because he found an efficient method of using them. Various surgeons have devised special forceps. The concave curve of Kalt's forceps[18] adjusts itself to the convexity of the anterior face of the lens and seems best adapted

to get down to grasp the lowermost portion of the capsule. The Elschnig forceps modified by Arruga[19] have been most popular and useful. The Sinclair forceps modified by Castroviejo[20] are of the cross-action type which, when relaxed and closed, hold the grasp of the capsule with a certain pressure, regulated by spring tension which may be adjusted to the desired degree. Arruga forceps blades are well adapted to grasping the area of the capsule just anterior to the superior equator of the lens as Verhoeff[21] has done, and it was for this reason that I adopted them.

New intra-capsular forceps.—In developing a new intra-capsular forceps, I combined different features—the length from Kalt, the angle and blades from Arruga, the stops from Verhoeff[22] and have added my own useful cylindrical handle (Figs. 2 and 3). The angle enables one to bring in the instrument from the side and not obscure the field with the hand as in using a straight shafted instrument. I have modified this forceps by using the Kalt concave curve of the shank for special use when I desire to take hold below and tumble the lens. Both of these forceps provide shafts long enough to fit easily into the hand, with cylindrical handles for graceful manipulations. They have the Verhoeff stops, one controlling the opening so that the 4 mm. opening can be adjusted without tension and placed ever so lightly on the lens capsule without pressure and the other controlling the closure so that the blades will not bite out a portion of the capsule unnecessarily. Various cups have been tried and

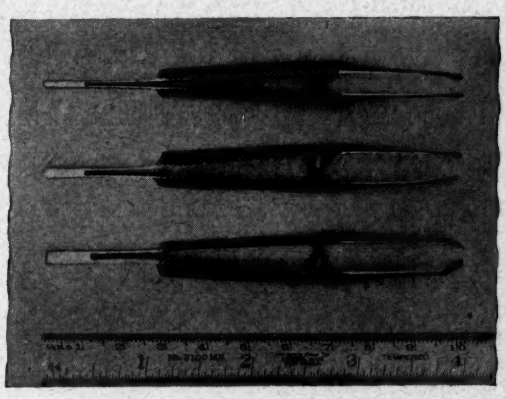

FIG. 2.

Two-third size photograph of:—1. Intracapsular forceps. 2. Iris forceps. 3. Corneo-scleral suture forceps. Front view.

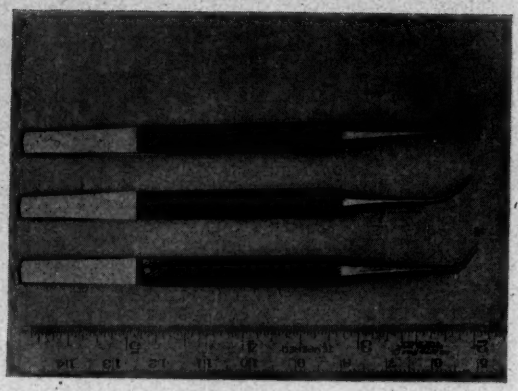

FIG. 3.

Two-third size photograph of:—1. Intracapsular forceps. 2. Iris forceps. 3. Corneo-scleral suture forceps. Side view.

that of Arruga has been selected and incorporated, but it has been offset by 1 mm. from the tip of the curved shank so that it will pick up the capsule only in the relatively small area of the blades and not have the shank behind the blades engage anything else. Such forceps permit the greatest ease of application, manoeuvrability and safety in handling the capsule and affecting various tensions that are purposefully transmitted to small areas of the zonules for simultaneous application and combination with the manoeuvres of pressure, rotation and direct zonulotomy by stripping the zonule from its attachment to the capsule.

Traction as it has been described by various surgeons includes pull tensions made by drawing the capsule vertically, horizontally both forward and transversely, tangentially and diagonally. Forceps are well adapted for the manoeuvres of traction and rotation (Verhoeff described a manoeuvre of " the upper part of the lens swing to and fro laterally with the forceps ").

ROTATION

The manoeuvre is a variation of traction, but is important enough to be considered separately. It causes the lens to turn in the circle of its circumference by traction on the capsule preferably from a point of advantage of grasp just anterior to the true equator of the lens. It is valuable because it puts a tension on the zonule directly surrounding the lens, emphasizing with traction the formation of a tense fold or plica of zonule opposite the point of traction and rotation which may be pressed upon through the

cornea for the greatest rupturing effect with the least effort. The same use of traction and rotation may be made in aiding the manoeuvre of direct rupture of the zonule by stripping it from its attachment to the capsule. There are two other uses for rotation which are valuable. The first is achieved when with the upper half of the zonule ruptured, the application of a second pair of forceps to the lens capsule makes possible further rotation. The zonule below may then be ruptured or torn by wheeling the lens around in the circle of its circumference. The second is the wheel rotation type of delivery rather than the flat sliding delivery, the former offering quite an advantage, there apparently being easier separation of the ligamentum hyaloidea capsulare and less drag on the bared hyaloid or face of the vitreous.

THE APPLICATION OF FORCEPS

Forceps may be applied, except when pressure is inadvisable, simultaneously with pressure from below, causing the lens to tilt, present and be supported by the instrument. Forceps may be (1) applied radially to the capsule below, as far below as can be reached conveniently; (2) to the central area of the capsule; (3) horizontally or vertically to the equatorial region directly above; and (4) to an area just to the right of centre above when the forceps are held in the left hand and *vice versa* when held in the right hand. For a right-handed surgeon it seems easier and more efficient to use the forceps in the left hand and the expressor instrument in the right hand.

1. When the forceps are applied below, the application is radial. It is possible to lift the lens vertically about 2 mm. toward the cornea, horizontally, transversely or cephaled to either side about 3 mm. and about the same diagonally or in rotation. Evidently these movements from the grasp below cause sufficient rupturing action on the zonule, for by the Knapp method with traction alone or by the Knapp[23], Lancaster[24], Torok[25], Stanculeanu[26], Elschnig[27], Arruga[19] and other methods of simultaneous traction and pressure, a large percentage of zonules may be ruptured and the cataracts delivered well and safely by tumbling them out in the capsule. 2. When the capsule is grasped at or near the centre it is apt to cause equal although insufficient tension on the zonule all around the equator. This will result in a lesser percentage of safe deliveries in capsule. 3. The grasp of the capsule tangentially just anterior to the true equator above according to Verhoeff, offers several advantages. (*a*) The surgeon can see better what he is doing, particularly when the corneal flap is lifted. (*b*) He can make localized traction directly away from the nearby zonule. (*c*) He can produce greater tension and direct it to

particular localized areas on the zonule as desired as he elevates the area of capsule vertically, makes traction to one side or the other and obtains greater rotational effect. (*d*) He can lift the lens away from the hyaloid and the vitreous. With the direct visual knowledge of what is happening, he can direct his pressure to the point where it will accomplish the most good with the least effort, to the narrow fold of zonule which is under tension, rupturing it more easily than if he applied much more pressure to a relaxed area of zonule or to a greater area in the same eye. When he wishes to produce direct rupture of the zonule by stripping it from its attachment to the capsule at the equator of the lens, he can by traction and rotation produce tension on the exact or certain area of the zonule which is to be touched for direct rupture. The traction superiorly also lifts the equator of the lens and zonule free from the relaxed vitreous to at least 3 mm. so that such manoeuvres are safe. Verhoeff said that the grasp of the capsule above could only be made if a complete coloboma of the iris has been made. I have demonstrated on numerous occasions that with the pupil dilated, the forceps can be made to grasp the lens tangentially, offering all of the advantages of the sliding delivery of Verhoeff. Certainly in difficult cases it is necessary to have as peripheral a grasp as possible so that the equator of the lens and the zonule may be lifted most easily and efficiently. In the grasp above, the horizontal tangential application of forceps above is better than a radial grasp because rotation to either side may be made without twisting the pedicle of the capsule by following the curve of the circle of the equator of the lens. Another advantage is that the surgeon may observe the behaviour of the capsule in the grasp of the forceps and, being aware of the imminence of a tear, change his tactics and avert it. He may shift to different portions of the capsule. A final advantage is that if a small tear in the capsule does develop, he can shift to another untouched portion of capsule above, and manoeuvring around the tear deliver the lens in capsule, or he may even go below to pick up the capsule and tumble the lens out. It might seem well when the manoeuvre of initial pressure alone has ruptured the zonule below that one would apply forceps below and tumble the lens out, but the application superiorly offers no difficulty, the zonule is fragile in such cases, the lens is lifted out easily and I believe the sliding delivery or rotational delivery is less disturbing to the vitreous than the tumbling delivery.

THE USE OF TWO PAIRS OF FORCEPS

It occasionally happens that with the technique of the application of forceps above, rotation to each side has effectively torn and released the zonule to the extent of the corneo-scleral incision and

there remains adherent the lower zonule still holding the lens. Pressure and traction may release this easily, but if not, I have found that a second pair of intra-capsular forceps applied judiciously behind the first pair may be used for further rotation and cause the further tearing of the zonule necessary for the delivery of the cataract.

THE REMOVAL OF THE RUPTURED CAPSULE

A method of removal of the remains of the capsule when it is ruptured in the extraction of cataract is called for in this discussion of rupture of the zonule. If a portion of capsule is visible in the incision or if with safe, relaxed patients the capsule can be identified when the corneal flap is elevated, then it can be picked up with a pair of intra-capsular forceps and judicious traction made upon it. No effort is made to draw out the entire capsule with one pair of forceps, but after a little has been withdrawn a second pair may be used nearer the incision, and so hand over hand the two forceps may effectively, easily and safely rupture the remaining zonule and remove the broken capsule completely or sufficiently.

Direct rupture of the zonule

(*a*) *Direct partial zonulotomy* by means of sharp instruments specially designed for the purpose as applied by Gradenigo[28] and others may, if properly used, accurately sever in part the zonular connections with the capsule, facilitating the complete rupture and permitting the delivery of the lens by extraction or expression, but the manoeuvre seems fraught with danger, particularly because with the collapse of the anterior and posterior chambers there is little space or margin of safety in which to work without disturbing the hyaloid and the vitreous.

(*b*) *Direct rupture of the zonule* by separating or stripping it from its attachment to the capsule superiorly under direct view is the new procedure which I have devised and used when the zonule proved resistant and resilient, difficult to rupture and not yielding to a safe degree of pressure, traction and rotation. I have stated previously that traction vertically with forceps lifted the lens and zonule at least 3 mm. safely away from the relaxed hyaloid and vitreous, furnishing adequate space for the manoeuvre of touching the zonule made tense by the vertical elevation or by rotation to one side or the other with a blunt instrument. A light touch under these conditions may cause the zonule to rupture in part, producing at first a small hole or dehiscence at the equator then, by further application of the instrument, a larger hole. Then by rotation, the zonule may be seen to tear further or it may be

FIG. 4.

Method of holding and rotating angulated iris spatula with Kirby cylindrical handle.

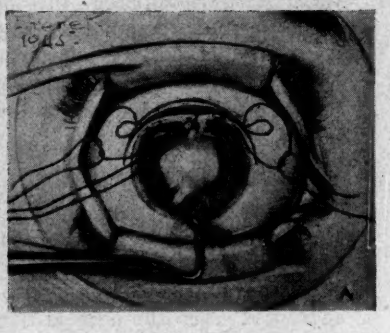

FIG. 5.

First point of preliminary pressure for palpation of the globe and test of fragility of zonule. Note the degree and position of the point of pressure and the effect of gaping of the incision directly opposite. Front view.

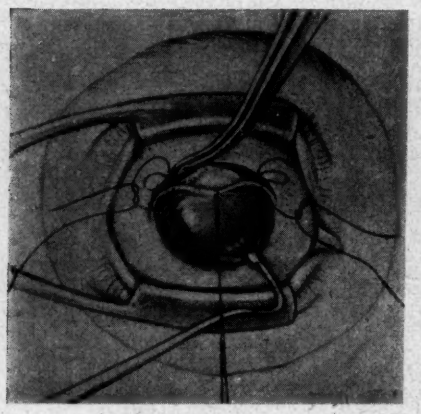

FIG. 6.

The corneal flap is retracted by the suture. Manoeuvre of rotation of the lens to the right, to the 120° meridian with pressure directly opposite at 300° meridian. The zonule is loose nasally. This is one of a series of three illustrations showing the point of pressure and the rotation of the lens. Front view.

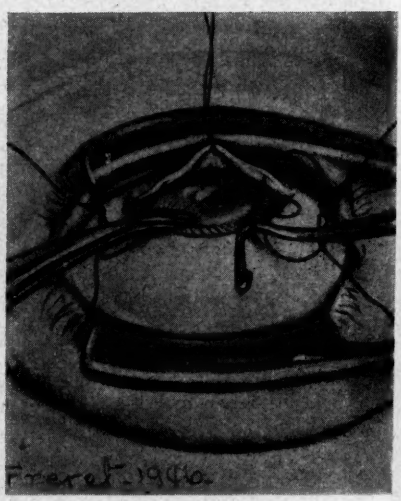

FIG. 7.

Lens rotated to the left and elevated making zonule tense at the left. Application of blunt elbow of lens expressor hook to tensed zonule directly at junction with the capsule for direct separation of the zonule from the equator of the lens. The appearance of the zonule is considerably intensified by the artist. Surgeon's view.

stripped from its attachment to the lens capsule by further use of this manoeuvre. The natural tendency has been to extend the successful use of the procedure to cases in which the cataract does not come away very easily by traction, pressure and rotation. Only in one case which has been reported previously have I had occasion to regret the use of the manoeuvre[29]. (Figs. 4, 5, 6, 7.)

The indications for direct rupture of the zonule

There is no way of determining before the operation that in a certain case a recommended or average degree of pressure or traction should be used, because the individual cases vary and often need more than simple pressure, traction or rotation either applied separately or simultaneously and in combination. The new manoeuvre of direct rupture of the zonule by stripping it from its attachment to the capsule under direct visual control is valuable and should be studied for use when pressure, traction and rotation are insufficient, and if when applied to greater degree may be traumatizing. It may also be indicated in cases of subluxation with viscid or fluid vitreous which is in communication with the aqueous of the anterior chamber. The escape of fluid vitreous, directly after the section has been made, causes the intra-ocular tension to fall so low that pressure is of no value at all in the effort to rupture the zonule. The presence of a resistant zonule in congenital or traumatic subluxation requires more than traction with a loop alone for non-traumatic delivery of the lens.

Clinically, in intracapsular surgery the ligamentum hyaloidea capsulare does not seem to be more than a coaptation of the hyaloid to the posterior lens capsule, the easiest manoeuvres releasing it. Only in the rare or exceptional case are the hyaloid and the vitreous apparently really adherent to the posterior lens capsule being drawn up in cone shape when the lens is lifted vertically. In the average case, the ligamentum hyaloidea capsulare is easily separated by the manoeuvres directed at the rupture of the zonule and no particular attention need be directed to the former.

The conditions under which direct rupture of the zonule is safe and practical

These may be stated as (1) the finding of a resilient zonule which resists rupture by the application of pressure, traction and rotation applied simultaneously and in co-ordination. (2) The proper relaxation of surgeon and patient. (3) Proper illumination by parallel beam spot light, extraneous light and glare being excluded. (4) The observation that no undue tensions exist in the eye under operation, there being no gaping of the incision, no prolapse of the iris, no forward position of the lens, hyaloid or

vitreous. (5) The corneal flap should be elevated to afford a direct view of the lens equator which is exposed by retraction of the iris, by removal of blood clots, serum or other fluid, so that the zonule which extends from the equator backward is visible when exposed to the air and viewed with a binocular loupe which affords two power magnification. (6) There should be about 3 mm. distance between the lens equator and the relaxed vitreous and hyaloid. (7) The zonule must be made tense as described to make the manoeuvre easily effective. If all of these conditions are not met, then the manoeuvres should not be attempted. Manipulation, particularly under conditions of poor visibility, may lead to rupture of the hyaloid. In general, it may be said that any surgeon who is acute in observation and does intra-capsular surgery well, should be able to carry out this manoeuvre.

I personally prefer the grasp of the forceps above for the reasons given. If a surgeon has had good success with the radial application of the forceps below, as many have had, he should not be asked to give it up. Cases which are easy or give moderate difficulty with the lower grasp will not be different with the upper grasp, but, when one has a difficult case which resists rupture under these conditions, one may not wish to continue to do that which is ineffective, and one may decide to try the grasp above and to apply the manoeuvres which have been described. Those who use the grasp above need not think that the first grasp with the forceps is the only one which they may take in a particular case. If, for example, it is found that the first grasp is an inefficient one, it may be released and a second one taken, or if in a certain case the first grasp is not near enough to the equator above or below, another one may be taken. Verhoeff has shown that with properly adjusted forceps the grasp may be shifted. In the case of the grasp above, the first forceps may be used to assist in downward traction on the lens capsule for better exposure of the pre-equatorial portion of the capsule.

Results

The results of intra-capsular cataract surgery in my hands during the past fifteen years, in comparison with a previous period of ten years of extra-capsular surgery, justify the continuance of the methods and procedures of the intra-capsular surgery described in this paper. In addition, I may say that the direct rupture of the zonule has been used for ten years. I have had only one occasion to regret its use. It may well be said to be feasible, conservative and desirable where the zonule is found too resistant and difficult to rupture after trial by the other means described.

Summary and conclusions

The rupture of the zonule of the crystalline lens is the *sine qua non* of the intra-capsular cataract extraction. The author has recorded his personal observations and experiences, to add them to the existing knowledge of the best atraumatic means of rupturing the zonule in various types of eyes with their different types of cataracts and zonules. The findings of a fairly large percentage of resistant zonules, in the author's surgical experience, is accounted for by the fact that the greater proportion of the cataracts operated upon are in the immature stage. In this period, both the capsule and the zonule are more nearly normal and resistant to rupture than in mature or hypermature cataracts, when both capsule and zonule may be quite fragile.

In observations of the applied anatomy during clinical surgery the zonule is observed as a lamella covering the fibres. The zonule is visible when exposed to the air and viewed with two power magnification. Dissections of early chick embryos brought out the finding that the zonular fibres may well be formed through elongations of protoplasmic adhesions established at the time of contact of the optic vesicle with lens ectoderm. The lamella may be added at the time of the formation of the tertiary vitreous.

The zonule usually ruptures in a small area first and gradually the entire zonule is separated. The place of rupture of the zonule is always at its union with the lens capsule. The latter is smooth after intra-capsular extraction.

The various manoeuvres for rupture of the zonule may be found classed under I, *Indirect rupture* (*a*) pressure from outside the globe, (*b*) traction on the lens or its capsule and transmitted to the zonule. This includes rotation of the lens in its capsule, (*c*) various combinations of these manoeuvres. II, *Direct rupture* of the zonule used alone or in combination with the various manoeuvres which cause indirect rupture.

Each of these manoeuvres is considered alone and in combination with others. The principles underlying the classical and well known operations of various authors are explained. Pressure alone may be found to rupture fragile zonules, but traction is preferred for delivery even in such cases. A combination of pressure and traction is more efficient than either alone. Rotation of the lens in its capsule is used particularly to produce conditions whereby pressure and traction may be co-ordinated to produce the greatest effect with the least effort. The method of shifting the grasp of the forceps or the use of a second pair of forceps to provide greater rotation when necessary is given.

The reasons for the preference of the grasp of forceps over that of the suction cup or the use of the loop or spoon are given.

Rotational delivery is preferred to the direct sliding or the tumbling methods.

The new method of feasible and practical direct rupture of the zonule by separating or stripping it from its attachment to the equatorial lens capsule has been partially considered and reported before. To the present date, the author has not found any similar method in the literature. The indications for its use, the determination of the cases in which resistance of the zonule is found, and the conditions under which direct rupture of the zonule may be applied successfully without injury to the hyaloid, presentation or loss of vitreous are given.

The author prefers the grasp of the forceps above for various reasons. If many others have had success with the grasp below, there is no need for them to change. But, if a difficult case is encountered, the grasp of the forceps may be shifted above and the manoeuvres, as described, may be tried. Those who use the upper grasp may find that they may shift the grasp above to one nearer the superior equator if necessary. A second pair of forceps may assist in this in drawing down the pre-equatorial capsule. The author reports the further application of the procedure as desirable, feasible and practical in difficult cases of cataract with resistant zonules. A follow-up of the cases in which this manoeuvre has been applied in a period of five years has proved that there has been no undue reaction, inflammation or infection, that the eyes have done well and that there has been good healing with good visual results.

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STUDIES ON THE INTRA-OCULAR FLUIDS*

1.—The Reducing Substances in the Aqueous Humour and Vitreous Body

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IN a recent paper to this Journal (Duke-Elder and Davson, 1948) a general review of the present position of our knowledge regarding the nature of the intra-ocular fluids was given; the present paper deals more particularly with our experimental work on the reducing substances (sugars, etc.) in the aqueous humour and the vitreous body. It has long been recognized that the concentration

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of reducing substances in the aqueous humour is low in comparison with that in the blood plasma (Adler, 1930; O'Brien and Salit, 1931) and the concentration in the vitreous body is still smaller. This has received three explanations.

(1) The low concentration in the ocular fluids has been ascribed to secretory activity. In view of the metabolic importance of glucose, however, it seems doubtful from a teleological standpoint whether a secretory system would be evolved providing a smaller concentration of this substance than can be produced by a simple mechanical process of filtration. Moreover, the site of such a secretion would presumably be the ciliary epithelium; and the secreted fluid, diffusing from this region through the pupil, would be available to both vitreous body and the anterior chamber so that we should not expect the concentrations in the two compartments of the eye to be significantly different: such a difference, as we shall see, occurs.

(2) Assuming that the aqueous humour is formed, at least partly, by a process of ultra-filtration whereby proteins are left behind to give a comparatively protein-free fluid, if a substance finds some difficulty in passing the barrier between the blood and the cavity of the eye but at the same time can find a free exit, it will be in a deficiency in the aqueous humour in comparison with the blood (Kinsey and Grant, 1942). In this view, the low concentration of glucose would be evidence not of a secretory mechanism in respect to this substance, but rather of the existence of a filtration process.

The mathematical formulation of the problem as set out by these authors has been criticised by us (Duke-Elder and Davson, 1944), and recently Palm (1948) has suggested an equation that promises to reconcile the opposing standpoints. We need not confuse the issue in this paper by introducing a mathematical discussion; it is sufficient to state that the effect postulated by Kinsey and Grant is a feasible one, but that it will depend to a great extent on the rate of penetration of the substance concerned. If the substance penetrates slowly and with difficulty, we may expect to find a deficiency of it in the aqueous humour when the steady state is achieved simply because it is drained away too rapidly to be adequately replaced. If the rate of penetration is comparatively rapid, on the other hand, as with ethyl alcohol (Palm, 1948), the effect will be negligibly small. The much lower concentration of glucose in the vitreous body, however, would be difficult to explain on a simple kinetic basis, especially since no flow through this structure has so far been demonstrated.

(3) A third explanation ascribes the deficiency of glucose to its absorption in the metabolic needs of the lens and retina. The lens

utilises glucose and this must clearly be derived from the aqueous humour and the vitreous body; as the glucose is abstracted from these sources more will diffuse through the blood-aqueous barrier to replace that used up, but since this diffusion process must wait on the utilisation of the sugar to cause the necessary concentration gradient, we must expect a steady state to be established with the concentration lower in the aqueous humour than in the blood plasma. In the case of the posterior cavity of the eye containing the vitreous body, we might not expect to find any greater deficiency since, although this structure is in apposition to the retina which consumes glucose at a great rate, the latter is directly supplied by blood from the capillaries of both the uveal and retinal circulations; there seems little reason why the vitreous body should be involved in this respect. If we assume, however, that the vitreous body receives its glucose, not exclusively by diffusion or secretion from the ciliary body, but rather by diffusion from the capillaries of the retinal and choroidal circulations, then the fact that these capillaries are supplying large quantities of glucose to the retina must influence the concentration in the plasma available for diffusion into the vitreous body. In other words the transudate derived from the choriocapillaris and retinal capillaries is so depleted of sugar that the available concentration for diffusion into the vitreous body is low.

In the present paper it will be shown that the low concentration of glucose in the intra-ocular fluids is predominantly, if not exclusively, a result of the metabolic factors discussed above.

EXPERIMENTAL

Static Studies. Great care was taken to avoid the hyperglycaemia associated with fear in the experimental animals; nembutal was used as anaesthetic, intraperitoneally in the cat and intravenously in the rabbit. In the latter animal it is impossible to avoid hyperglycaemia, and before fluids were removed the animal was "equilibrated" for some hours with its head projecting from a bleeding-box. For comparison of normal and aphakic eyes this equilibration was not so important and was generally omitted. Blood was withdrawn from the cat by arterial puncture, and from the marginal ear vein of the rabbit after vaso-dilatation with toluene. Sugars were determined in duplicate by the Hagedorn-Jensen technique (1923) on Somogyi (1930) filtrates of the various fluids; sucrose was determined by estimating the reducing value of the fluid before and after hydrolysis in 0·1 NH_2SO_4 (15 min. at 100° C.). The difference between duplicates rarely exceeded 1%, except if the reducing value was low when it amounted to 2%. Removal of the lens was carried out by the standard surgical procedure for extracapsular extraction. (Intracapsular extraction is impossible in these animals owing to the adherence of the vitreous to the posterior lens capsule.)

Dynamic Studies. The general principle was to maintain a constant high level of a given sugar in the blood by continuous intravenous infusion of an isotonic solution in 6% gum acacia under nembutal anaesthesia. Rapid elimination of the injected sugar was prevented by tying the renal arteries. One eye was, in general, removed before the injection, to estimate the initial reducing value of the intra-ocular fluids, and the other after a known time interval. With sucrose, which is

estimated independently of the reducing substances in the fluids, the preliminary removal of one eye is unnecessary. After enucleation, the aqueous humour was withdrawn and the eye was then frozen in solid CO_2. When hard, the eye was cut into two or more pieces as described later; the frozen pieces of vitreous body were filtered through glass-wool as they melted in order to break down the gel structure. Blood and aqueous humour were immediately placed in tubes surrounded with ice.

RESULTS

1. STATIC STUDIES: THE CONCENTRATION OF REDUCING SUBSTANCES.

(*a*) *The normal distribution.*

The concentrations of glucose in the aqueous humour, vitreous body, and blood plasma of rabbits and cats are shown in Table I.

TABLE I

GLUCOSE CONCENTRATIONS (MG./100G.H_2O) IN PLASMA AND INTRA-OCULAR FLUIDS

	Plasma	Fluid		R_A=aq /pl.	R_V=vitr./pl.
		Aqueous	Vitreous		
Rabbit	131	116	56	0·89	0·425
	133	118	66	0·89	0·495
	142	110	74	0·78	0·52
	149	128	87	0·86	0·58
	160	134	73	0·84	0·46
	163	145	82	0·89	0·50
Mean	—	—	—	0·86	0·49
Cat	125	95	64	0·76	0·51
	89	73	55	0·82	0·615
	92	78	52	0·85	0·565
	119	86	61	0·72	0·51
	104	67	44	0 64	0·425
	121	89	58	0·74	0·48
	103	89	64	0 87	0·62
Mean	—	—	—	0·77	0·53

It is seen that the concentration of glucose in the aqueous is less than that in the plasma by some 15 to 20%, while that in the vitreous is still less, being approximately half that in the plasma. The results on the cat amply confirm those of Adler (1930); the low glucose content of the vitreous body is striking.

(*b*) *Distribution in the aphakic eye.*

There are two main loci of sugar utilization in the eye—the lens

and retina. That the lens modifies the sugar content of both the aqueous and vitreous humours is shown in Table II, in which some typical results on rabbits and cats are presented. The lens

TABLE II

GLUCOSE CONCENTRATIONS (MG./100 G. H_2O) IN FLUIDS OF NORMAL AND APHAKIC EYES

	Interval after extraction (weeks)	Plasma	Fluid			
			Normal aqueous	Aphakic aqueous	Normal vitreous	Aphakic vitreous
Cat No. 1	4	89	64·5	83	—	—
	6	98	72	83	—	—
Cat No. 2	7	88	66·5	81	—	—
	9	104	66·5	83	44	57
Cat No. 3	3	95	76	81	—	—
	4	—	74	81	—	—
	6	88	76	82	45	53
Rabbit No. 1	3	214	165	149	—	—
	5	183	127	99	—	—
	6	185	166	147	—	—
	7	208	157	129	99	107
Rabbit No. 2	3	161	152	145	—	—
	5	126	103	105	—	—
	6	145	126	121	—	—
	7	178	162	158	99	111
Mean (9 rabbits)	7/14 weeks	152	124	117	87	96

was removed from one eye, and at various intervals after the operation, when the eye had quietened down, aqueous humour was withdrawn from both; finally, both eyes were enucleated. In the cat, the increase in the concentration in the aqueous humour after extraction of the lens was pronounced (20% or more) in two cases, whilst in the rabbit it was much smaller; in fact, there may be an actual decrease, as in rabbit No. 1. This seems to be due to diffusion backwards through the pupil into the vitreous body, since rabbit No. 1, in which this effect was most marked, had a wide iridectomy and dilated pupil, whereas rabbit No. 2 had no iridectomy, a constricted pupil and some opaque lens matter partially covered the pupillary aperture. Similarly cats Nos. 1 and 2 had portions of opaque lens material remaining in the pupil, whilst in cat No. 3 the pupil was wide and completely unobstructed. The mean for nine rabbits shows a 6% decrease in the aqueous humour in the aphakic eye. The vitreous body showed a

large increase in the cat (30%) and a smaller increase in the rabbit. It is to be remembered, however, that the normal eye of the rabbit contains a higher concentration of ascorbic acid than the aphakic eye (Goldman and Buschke, 1935) and, since this substance contributes to the reducing value of the aqueous humour, and is therefore included in the estimations, the increase in the concentration of glucose in aphakia in this animal is partially masked by the decrease in the concentration of ascorbic acid.

The fact that the fluids of the aphakic eye do not show sugar concentrations equal to that in plasma suggests that the retina is utilizing glucose. If glucose is consumed by the retina of the enucleated eye, the concentration of glucose after incubation should be less in the periphery than in the centre of the vitreous body.

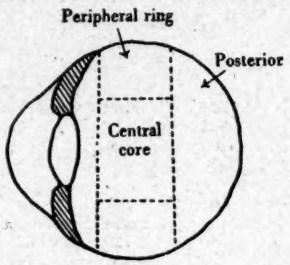

FIG. 1.

Sectioning of the frozen vitreous before and after incubation.

(c) *Concentration in the incubated excised eye.*

The two eyes of a cat were removed; one was frozen immediately, while the other was placed in a boiling tube in the bottom of which there was cotton-wool moistened with 0·9% NaCl; the tube was immersed in a bath at 38-40° C. After 2 hrs. the eye was frozen. The eyes were sectioned as indicated in Fig. 1, giving a large central disk and a thinner posterior cap of vitreous body. With a cork-borer the central disk was divided into a core and peripheral ring, the latter about 3 mm. wide. The *differences* in the glucose contents of the aqueous humour and of the various parts of the vitreous body *before and after incubation* were as follows:

		GLUCOSE DIFFERENCE mg./100 g.
Vitreous body	Core of central disk	15
	Periphery of central disk	40
	Posterior cap	30
Aqueous humour	—	27

The result leaves little doubt that the retina is responsible for at least a part of the consumption of glucose in the posterior cavity of the eye. If the lens only were consuming glucose, the core of the central disk would have shown the greatest loss since it was in immediate contact with the lens; on the other hand, the greatest loss is in the peripheral regions next to the retina.

In the eye, immediately after enucleation, the glucose is apparently not uniformly distributed through the vitreous body; Adler (1930) has shown that in the frozen eye the anterior half of the vitreous body contains more sugar than the posterior. In a series of nine rabbits we have found that if the middle disk (Fig. 1 (a)) of the frozen vitreous body was divided into a central core and a peripheral ring, the latter invariably contained the higher glucose concentration. It is possible that these differences in concentration are, at least in part, artefacts resulting from the freezing process, so that it is not justifiable to draw definite conclusions from the observed concentrations regarding the relative extents to which glucose is utilized in the different parts of the eye. The finding of a lower concentration in the central core is, however, reasonable, since it is in immediate contact with the lens. On incubation, however, this relationship is invariably reversed, both in the cat and rabbit; in these circumstances we must assume that the retina draws on the glucose in the vitreous body owing to the absence of the retinal and uveal circulations.

(*d*) *Concentration in mydriasis and miosis.*

A series of experiments were done to determine the concentration of reducing substances in the aqueous humour in mydriasis and miosis. One eye of a cat was treated with eserine and the other with atropine; after about 2 hrs. the aqueous humours were withdrawn from both eyes. The mean results for four cats (two of them kittens) were as follows:

	Glucose mg./100 g.
Atropinized eye	70
Eserinized eye	75
Plasma	107

This rise in the concentration of reducing substances in miosis may, in part, be considered due to a reduction of the area of lens exposed to the aqueous humour. Alternatively, eserine, by breaking down the blood-aqueous barrier, and by increasing the dialysing surface of the iris, may permit a readier penetration of glucose from the blood. It is to be noted that if glucose reaches the anterior chamber by way of a flow from the posterior chamber through the pupil, miosis should restrict this flow and so produce a lower concentration.

(*e*) *Concentration in the plasmoid aqueous.*

Again, it may be expected that the aqueous humour formed immediately after the emptying of the anterior chamber (paracentesis) should have a higher concentration of glucose, since the lens will not have had time to re-establish a steady state. The results of a typical experiment are as follows, the 'second' re-formed aqueous humour being the fluid formed after the successive withdrawals of the original and 'first' re-formed aqueous humour:

	Glucose mg./100 g. H_2O
Normal aqueous humour	62·5
First re-formed humour	83·5
Second re-formed humour	85·5
Plasma	89

In no instance, however, did the glucose concentration in the re-formed fluid equal that in the plasma.

2. KINETIC STUDIES: THE RATE OF ENTRY OF REDUCING SUBSTANCES.

The permeability of the membranes of the eye to the following sugars was investigated: glucose, galactose, 3-methyl glucose, xylose and sucrose. 3-methyl glucose is a synthetic compound which is apparently not phosphorylated *in vivo* (Campbell, unpublished) and was thought, on this account, to be unlikely to be secreted.

Detailed results of seven experiments with glucose are presented in Table III in order that the animal-to-animal variations may be appreciated. Constants indicating the rate of penetration into both aqueous humour (K_A) and vitreous body (K_V) have been calculated in accordance with the equation of Davson and Quilliam (1940).*

Owing to the impossibility of obtaining large supplies of xylose no more than six experiments could be carried out; consequently Student's '*t-test*' for the differences between means of small samples was applied successively to the mean values of K_A/K_V for xylose and the individual hexoses; the values of P_S (Yule and Kendall, 1940), indicating the probability that the values of t so computed would occur by chance, are included in the table. With 3-methyl glucose and galactose the differences in the ratios are significant; with glucose, where greater variability was encountered, the difference is not significant. The large increase of the ratio K_A/K_V on passing to the disaccharide is clearly significant.

* The equation is only approximate owing to the utilization of sugar by the eye, but in view of the large animal-to-animal variations refinements seem unnecessary. When the plasma reducing value is raised by several hundred per cent. the steady state finally achieved tends to equality of concentration expressed as mg./100 ml. as opposed to mg./100 g. H_2O (*i.e.*, the true concentration in the plasma is about 7% higher than in the aqueous humour), and for this reason the former unit has been used in these kinetic studies.

TABLE III

THE RATE OF PENETRATION OF GLUCOSE INTO THE AQUEOUS HUMOUR AND VITREOUS BODY OF THE CAT

Plasma (mg./100 ml.)	Aqueous (mg./100 ml.)		Time (hr.)	$100K_A$	$100K_V$	K_A/K_V
	A_1	A_2				
280	94	254	2.0	38	11	3.45
290	140	188	0.5	33	16.5	2.0
265	92.5	144	0.75	20.5	12	1.7
266	130	232	2.0	30	10	3.0
280	104	202	0.62	57	7	8.1
597	112	238	0.47	31	10	3.1
439	88	233	0.75	30.5	9	3.4
Mean	—	—	—	34	11	3.1

In the above table A_1 is the initial concentration in the aqueous humour; A_2 the concentration in the aqueous humour after the blood concentration, P had been maintained for t hours. K_A is given by the equation:

$$K_A = \frac{kA}{V} \times \frac{1}{2 \cdot 303} = \frac{1}{t} \log \frac{P - A_1}{P - A_2}$$

where k is the true permeability constant, and A and V are the area and volume of the system respectively. K_V represents a similar constant derived from the concentrations in the vitreous body.

TABLE IV

PENETRATION OF DIFFERENT SUGARS INTO THE EYE FLUIDS OF CATS

Sugar	No. of cats	$100K_A$	$100K_V$	K_A/K_V	P_S
Xylose	6	37 ±2·7	16·5 ±1·5	2·2	—
Glucose	7	34 ±2·2	11 ±0·8	3·1	0·125
Galactose	9	33·5 ±2·3	9·5 ±0·9	3·5	0·006
3-Methyl glucose	5	36·5 ±2·9	11 ±0·5	3·3	0·02
Sucrose	9	4·9 ±0·6	0·29 ±0·05	17	—

K_A and K_V have the same meaning as for Table 3. P_S is the probability that the value of Student's t, computed from the mean xylose K_A/K_V and the hexose K_A/K_V, would occur by chance (Yule and Kendall, 1940). Standard errors are also shown.

Table III shows a consistent difference in rates of penetration into the aqueous humour and vitreous body, the rate for the aqueous humour being some three times greater. In Table IV the results for the remaining sugars are presented in the form of the constants, K_A and K_V only. The following points may be noted:

(*a*) The rates of penetration of monosaccharides, whether pentoses (xylose) or hexoses into the aqueous humour are not significantly different; the disaccharide, sucrose, on the other hand, penetrates very much more slowly.

(*b*) The rates of penetration of the monosaccharides into the vitreous body show a significant difference. The pentose, xylose, shows the most rapid entry, a little over one-half its rate of penetration into the anterior chamber ($K_A/K_V=2{\cdot}2$). The rates of penetration of the hexoses are all of the same order—about one-third of those into the aqueous humour ($K_A/K_V=3{\cdot}1$ to $3{\cdot}5$). In the case of sucrose, penetration is very small indeed; the factor is one-seventeenth ($K_A/K_V=17$).

The results suggest that *the barrier separating the blood plasma from the vitreous body is more selective than that separating it from the aqueous humour;* thus the latter apparently does not discriminate between a hexose and pentose, whereas the former appears to do so; as the molecular size is increased the greater selectivity of the barrier separating the vitreous body from the blood is shown in the increasing value of K_A/K_V.

The Site of Entry. The differing relative values of K_A and K_V for any given sugar suggest that this substance can enter the eye from other regions than the ciliary body; if penetration took place only from the ciliary body it would be expected that, after maintaining the blood sugar level at a high value for (say) an hour,

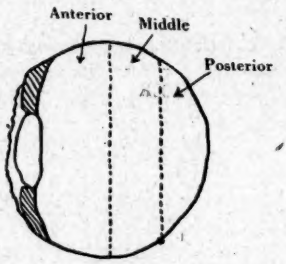

FIG. 2.

Sectioning of the frozen vitreous body before and after diffusion experiments, the aqueous humour having been removed.

the concentration in the part of the vitreous body most remote from the ciliary body would be smaller than in that nearest. In thirteen different experiments, the eyes, after removal of the aqueous humours, and freezing, were cut approximately as in Fig. 2; these gave as mean volumes for the various sections:

posterior, 0·35 ml., middle, 0·43 ml., and anterior, 0·63 ml. The different parts were analysed and the results are shown in Table V. It will be seen that, for the control eyes, the mean concentration in the middle section was 67 mg./100 g. H_2O, being 92% of that in the posterior section; after a high blood-sugar had been

TABLE V

CONCENTRATIONS OF SUGAR (MG./100 G. H_2O) IN THREE SECTIONS OF VITREOUS BODY AFTER MAINTAINING A HIGH BLOOD CONCENTRATION FOR A DEFINITE PERIOD, COMPARED WITH THE CONCENTRATION IN THE CONTROL EYE. MEAN RESULTS OF THIRTEEN EXPERIMENTS

	Section of vitreous body		
	Posterior	Middle	Anterior
Control	73	67	75
Test	124	98	113

maintained for about 1 hr. the average concentration in the middle section was 98 mg./100 g. H_2O, being only 78.5% of that in the posterior section. The results certainly suggest that *the locus of diffusion into the vitreous body is not confined to the ciliary body,* but occurs throughout the whole posterior segment of the eye. It must be remembered, however, that deductions from the concentrations of dissolved material in the frozen eye are to be accepted with caution. To minimize any such fallacy, conditions of freezing were kept as uniform as possible so that disturbances in distribution would operate to the same extent in the control and test eyes, and it would seem that the results are significant.

These results prompted an inquiry into the site of entry of substances into the aqueous humour; if diffusion takes place entirely from the ciliary body, they must enter the anterior chamber through the pupil; and a variation in the size of the latter might modify the rate of appearance. Diffusion experiments were carried out as before, but one eye of the cat was eserinized and the other atropinized. If diffusion takes place only from the ciliary body the rate of entry should be less in the eserinized eye with its extremely narrow slit-like pupil. The results are shown in Table VI and confirm those in the concentration experiments previously recorded; invariably the rate of entry of sugar into the eserinized eye was more rapid than into the atropinized eye.

These results strongly suggest that the primary effect of eserine on the penetration of sugars into the eye is to diminish any block to the passage of sugar presented by the blood-aqueous barrier

TABLE VI

THE RELATIVE RATES OF ENTRY OF SUGARS INTO ATROPINIZED AND ESERINIZED EYES

Sugar	Time (min)	Atropinized eye	Eserinized eye
Galactose	40	152	214
Galactose	27	215	239
Glucose	60	242	257
Xylose	41	191	199
Galactose	62	150	164
Sucrose		18	28
Sucrose	110	38	51

The figures represent sugar concentration in the aqueous humour, in mg./100 g. H_2O, after maintaining a high sugar concentration in the blood for a given time.

(as, for example, by inducing vaso-dilatation) and/or to increase the area across which passage is possible (the surface of the iris). If such were its effect, we should expect the influence of the drug to be greater proportionately on a substance that penetrates the barrier with difficulty. The bracketed results in Table 6, which describe the effect of eserine on the penetration of both galactose (penetrating comparatively easily) and sucrose (penetrating with difficulty) show that this effect is clearly much stronger with the latter substance. On purely mechanical grounds we should expect a less ready flow of aqueous humour through the pupil when the latter is a mere slit, and the fact that sugars actually penetrate into the anterior chamber at a faster rate would suggest either that flow through the pupil is not affected by its size or that the partial breakdown of the blood-aqueous barrier or an increase in its area obscures any effect of diminished flow.

DISCUSSION

There seems little doubt from the results of the first part of this paper that metabolic factors play an important part in determining the low concentration of reducing substances in the intra-ocular fluids. The influence of the lens is seen in the higher concentration in aphakic eyes; but in these the aqueous humour and plasma levels still differ by a factor of some 10% in the cat.

From the observed concentrations and the constant, K_A for glucose, it is possible to calculate the rate of absorption of glucose from the anterior chamber; it amounts to about 0·15 mg./hr., a figure not inconsistent with the known sugar utilization of the

lens (Kronfeld and Bothman, 1928). From the posterior cavity of the eye the lens and retina may both extract glucose, and the concentration in the vitreous body is therefore less than in the aqueous humour. The regional distribution of glucose in the vitreous body is explained by this dual consumption. The aqueous humour immediately re-formed after paracentesis has a glucose concentration differing by only about 5% from that of plasma; here the effects of the activity of the lens and diffusion through the pupil are minimized, and one might expect to find the concentrations equal. Three factors, however, must be taken into consideration. In the first place, a small fraction of the sugar in the blood is probably bound to the proteins of the plasma and is therefore not free to diffuse across a membrane impermeable to protein. In the second place, the blood used for comparison was arterial; the eye is an organ with a very high metabolism and we may therefore expect an arterio-venous difference in sugar concentration. It is to be remembered that differences as large as 39 mg./100 g. between the blood-sugar content of the carotid artery and vortex vein have been reported; the greater portion of this discrepancy is probably due, however, to activity in the more posterior parts of the eye. The glucose concentration in the capillary plasma is almost certainly, on the average, less than that in arterial plasma. Finally, the non-sugar reducing substances in the plasma represent a considerable fraction of the whole (27 mg./100 ml. according to Somogyi, 1927); the membrane separating the aqueous humour from the plasma has a high degree of selectivity in respect to nitrogenous compounds (unpublished) and it is possible that the re-formed aqueous humour, formed by a rapid process of ultra-filtration and therefore not necessarily equivalent to a dialysate, contains a lower concentration of non-sugar reducing substances than would be the case if time were permitted for dialysis to proceed to completion. The behaviour of sucrose is a case in point; if a high sucrose concentration is maintained in the blood of the cat, it is found that the re-formed aqueous humour after paracentesis has a sucrose concentration only 60% of that in the blood.

This consideration brings us to the viewpoint put forward by Kinsey and Grant (1942); according to their treatment, the deficiency of glucose in the aqueous humour is due to the difficulty of entry of this molecule during a filtration process and the freedom of its exit in the drainage of aqueous humour from the anterior chamber. That such a retention is theoretically feasible we have indicated in the introduction to this paper and is moreover confirmed by the experiment on sucrose described above; sucrose, however, penetrates the eye with great difficulty, whereas glucose enters at a rate some seven times greater. Without an exact mathematical analysis, which so far has not been made owing to the difficulty in assessing one of the parameters in the process, it is not possible to state on theoretical grounds whether the effect of this retention will manifest itself measurably in respect to glucose. As we have indicated earlier, we have some evidence that

when the blood sugar level is raised considerably, so that metabolic consumption becomes proportionately less significant, glucose penetrates the eye and approaches a steady state in which the concentration, expressed as mg. 100 g. H_2O, is some 7% lower than in the plasma. This suggests that the effect of retention is measurable in the case of glucose, but that it is by no means sufficient to account for the 23% difference pertaining in the normal animal.

It is difficult to assess experimentally the true steady-state with glucose since a high blood sugar concentration must be maintained over a period of hours; and during the last hour this concentration must be kept constant. The matter is further complicated by the non-specificity of the usual methods for determining sugars. So far as the aqueous humour is concerned, therefore, we may say that the low concentration of glucose is due mainly, if not entirely, to metabolic factors; the retention factor of Kinsey and Grant, whereas it probably plays an important rôle in the steady-state achieved by sucrose and other substances penetrating more slowly, is not the determining factor with respect to glucose.

With urea, on the other hand, it would seem that for the low concentration, described first by Adler (1933), and later confirmed by a number of authors and also in our laboratory, the explanation of Kinsey and Grant is at least theoretically valid; urea penetrates at less than half the rate of glucose (Davson, Duke-Elder, Maurice, Ross and Woodin, 1949), and here metabolic influences may be ruled out.

The kinetic studies tend to confirm this view of the steady-state; the barrier between the plasma and the aqueous humour shows no special selectivity towards glucose but permits galactose, the synthetic 3-methyl glucose, and the pentose, xylose, to pass at about the same rate. If any secretory activity were involved, one might expect, by analogy with intestinal absorption, to find appreciable differences in rates, particularly in the case of the synthetic sugar which we might not expect to be secreted at all and certainly not at the same rate as glucose. The slow rate of penetration of sucrose is in agreement with some earlier preliminary work on the dog (Weld, Feindel and Davson, 1942) in which it was shown that this molecule represents the limiting size for sugar penetration, the trisaccharide, raffinose, hardly penetrating at all. So far as these results go, it would appear that a purely physical explanation of diffusion depending on molecular size, meets the case.

The striking difference in selectivity between the barriers separating the aqueous humour and vitreous body from the blood is of some significance; hitherto it has been considered sufficient, in the interpretation of intra-ocular dynamics, to study the penetration of substances into the aqueous humour only. The existence of this more selective membrane lining the posterior cavity of the eye may well mean that the composition of the vitreous body plays a part of some importance in the determination of the intra-ocular pressure; if there is any secretion into the eye

it will obviously be more effective in modifying any difference between the osmotic pressures of the ocular fluid and plasma if the secreted substance does not leak away rapidly.

The question may reasonably be raised whether the differences in K_A and K_V represent actual differences in permeability constants. The constants K_A and K_V contain the factor A/V, the ratio of area of membrane to volume of fluid, and if this is not the same for the two compartments of the eye the constants are not directly comparable. In the cat, the volumes of aqueous humour and vitreous body are roughly in the ratio of 1:1·5, but it is impossible to state the effective areas of membrane; in view of the large number of ciliary processes, it would appear that the area available for diffusion into the vitreous body is considerably the greater, in which case the difference between the true permeability constants would be greater still. It is not necessary, however, to know the values of A/V in determining whether the differences in K_A and K_V represent differences in permeability constants; if the membranes had identical characteristics we should expect the ratio K_A/K_V to be the same for different molecules; as we have seen, this is by no means true for the ratio increases with increasing size of molecule. In a similar way, the effects of different viscosity and different rates of mixing in the two fluids should manifest themselves to approximately the same extent for different molecules.

It is of interest to assess the actual value of k, the true permeability constant for hexoses, from an assumed area-to-volume relationship. k is given by:

$$k = \frac{KV}{A} \times 2{\cdot}3 \text{ (Davson and Quilliam, 1940).}$$

Conventionally, k is expressed as the number of g.-mol. of the substance penetrating $1\mu^2$ of surface in 1 sec. when the concentration difference is 1 mol./1. If the volume of the aqueous humour is taken as 1 ml. and the diffusing surface as 1 cm.^{2}, k comes out at approximately 2×10^{-15}. This compares with a value of $7{\cdot}8 \times 10^{-16}$ for the penetration of urea into the ox erythrocyte, an instance of high permeability. The effective area of diffusing surface for the anterior chamber is, of course, likely to be very much higher than 1 cm.^{2}; if the area-to-volume relationship were comparable with that in the erythrocyte where 1 ml. of cells has an area of about $1 \times 10^{12}\mu^2$ (Ponder, 1934), k becomes 2×10^{-19}. Such an extreme instance of area-to-volume relationship is unlikely to apply to the eye, but even this value of k suggests that the rate of penetration is comparatively high when it is appreciated that the penetration of the smaller molecule, erythritol, into plant cells gives constants ranging from 7×10^{-21} to $1{\cdot}3 \times 10^{-19}$ (*vide* Davson and Danielli, 1943).

It therefore seems likely that the penetration of hexoses into the eye is a rapid permeability process; this fact, and the absence of a significant difference in rate between hexoses and the pentose, might suggest a penetration by way of water-filled pores, *e.g.*, through the intercellular spaces of the iris capillaries and iris endothelium. Evidence derived from a study of the penetration of some other substances, however, is against this simple mechanism and it is more probable that the comparatively rapid rate of penetration of sugars is an instance of cell membrane specialization of the kind described by Davson and Reiner (1942).

In conclusion we feel we must draw attention to the significance of the results of kinetic experiments and their mathematical formulation. In our treatment of the process of penetration of sugars into the eye we have applied purely kinetic principles such as

would apply to the migration of substances across an inert membrane; the complications introduced by a possible flow of aqueous humour, as first pointed out by Kinsey and Grant (1942) and modified by Duke-Elder and Davson (1943) and Palm (1948), in no way affect the fundamental principles of the kinetic treatment provided that there is a sufficient head of pressure in the blood capillaries to make the postulated concentration differences feasible. The existence of a flow of aqueous humour through the pupil and out at the angle of the anterior chamber has been abundantly demonstrated by clinical observations, by the recent observations of Ascher on aqueous veins (1942) and by a variety of experimental procedures on laboratory animals (Friedenwald and Pierce, 1932, and Bárány and Kinsey* on the rabbit: Davson, Duke-Elder and Maurice, unpublished, on the cat): this will be made the subject of another paper but, in general, it would seem that the aqueous humour is replaced at a rate of some 1 to 2% of its volume per minute. Such a flow could, theoretically, be maintained by a simple mechanical filtration process although the work of Bárány (1946, 1947, *a*, *b*, *c*, 1948), makes this doubtful. Moreover, evidence has been accruing from this laboratory that secretory processes are at work in the elaboration of (at any rate) certain constituents of the aqueous humour (Duke-Elder and Davson, 1948): thus the osmotic pressure of the aqueous humour is greater than that of plasma (Benham, Duke-Elder and Hodgson, 1938), as also is its content of sodium and chloride (Hodgson, 1938: Davson, 1939: Davson and Weld, 1940: Davson, Duke-Elder and Maurice, 1949).

As Bárány and Davson (1948) have emphasised, equations derived to explain the penetration of substances by a secretory mechanism (*e.g.*, that of Kinsey and Grant, 1942) have essentially the same form as those derived on a simple kinetic basis once the factor of drainage is introduced; there is thus nothing in the kinetics of the penetration of the various substances so far studied, considered as evidence by itself, that need necessarily rule out the secretory view of the mode of formation of the aqueous humour. In view of the arbitrary assumptions necessary for the formulation of equations dealing with secretory processes, arguments on purely kinetic grounds tend to be sterile, and more subtle and discriminating modes of investigation are necessary.

SUMMARY

1. In the cat and rabbit, the glucose concentrations in the aqueous humour and vitreous body are lower than would be

* Personal communication from Dr. Bárány.

expected on the basis of a simple diffusion equilibrium with the plasma. Experiments indicate that this deficit of glucose is due to the metabolism of both the lens and the retina.

2. The rates of penetration of glucose, galactose, 3-methyl glucose, xylose and sucrose into both aqueous humour and vitreous body of the cat's eye have been measured, and constants, K_A and K_V, proportional to these rates, have been calculated. No significant differences in rate of penetration into the aqueous humour were found with the first four sugars; but sucrose (a disaccharide with a larger molecule) penetrated much more slowly: polysaccharides (inulin, raffinose) cannot cross the blood-aqueous barrier in significant amounts in the normal state. The penetration rates of all sugars into the vitreous body were consistently smaller than into the anterior chamber, and an analysis of the results indicates the existence of a more selective barrier to diffusion into this part of the eye than that separating the aqueous humour from the blood. The possible physiological significance of this difference is discussed and the importance of including the vitreous body in any study of intra-ocular dynamics is stressed.

3. The rates of penetration of sugars into the aqueous humour with a constricted and a dilated pupil have been studied and it seems likely that a considerable amount of diffusion into the anterior chamber takes place from the iris. Evidence is presented which suggests that the locus of diffusion into the vitreous body is not confined to the ciliary body but occurs from all the surrounding vascularized tissues.

4. It would appear that the entry of sugars into the eye can be explained on the basis of a process of diffusion. That secretory activity is not involved in the process (so far as these substances are concerned) is suggested by (*a*) the variation of the rate of entry with the molecular size of the substances concerned, (*b*) the similarity of the rate of entry of natural sugars (*e.g.*, glucose) with synthetic sugars not found or phosphorylated in the body (3-methyl glucose), and (*c*) the evidence that sugars enter the ocular cavity from all the surrounding vascularized tissues.

5. By assuming limiting values for the area-to-volume relationship for the aqueous humour, it is possible to calculate the true permeability constants for the hexoses in the conventional units; the computation suggests that penetration is rapid in comparison with that of analogous lipoid-insoluble molecules diffusing into plant cells.

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THE STABILISATION OF THE REFRACTION AND ITS RÔLE IN THE FORMATION OF AMETROPIA*

BY

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THE well-known doctrine of the late Swiss ophthalmologist Steiger about heredity in refractive errors (and in myopia) has not been generally accepted till to-day, although renowned authors supported it.

Vogt and his school played the leading party in this. On the other hand high scientific authorities opposed this and the dispute became sometimes very vigorous. Recently it was Lindner who was vehement in opposition to it, finding the cause of the " myopic process " once more in near work.

The question is of great practical significance. It is of vital importance to a young myopic patient whether he is allowed to read and study or not. As an example I can quote a case of a highly educated person, with stable myopia of 5 dioptres in healthy eyes. The myopia began 30 years ago in his 10th year. His parents were then strongly advised to place him in some rural occupation on account of his beginning myopia. It was only the sound common sense of the mother that averted such an unlucky turn in her boy's future.

As it is known, Steiger derived the refraction from the variation and combination of the optical elements, these being each separately inherited. An eye with a given axis results in hypermetropia, emmetropia, or myopia depending on the adjoined lower or higher refractive power. Since every component and the resulting refractive power has its own curve of variation, Steiger combined the 2 spherical ametropias together with emmetropia in one continuous line of refraction, H standing on the left, M standing on the right side of E.

Although Steiger founded the origin of myopia absolutely on heredity, and did not allow any exogenous factor, nevertheless near work played an important rôle in his theory. According to him myopia arose out of the curve of refraction adapting itself to the changed circumstances of life during a century of evolution, in the sense of Darwin's theory of selection and elimination. (Of course we have to complete it now with the newer concept of mutation.) With the growing importance of near

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work the originally eliminating factor M turned, according to Steiger, into a selective value. Myopic variations could survive and multiply. Thus myopia is an acquired feature, but it was acquired by the race and not by the individual.

Neither Steiger nor his followers took into consideration the important fact that there exists between M and the two other refractions, E and H, in one respect a sharp contrast, that does not allow them to be placed straightaway into one biological unit: H, and partly E, remain mostly unchanged from early childhood, whereas M begins later and progresses sometimes till adult age. In other words, the refraction of the hypermetropic and emmetropic eye is mostly stabilized early in life, on the other hand, the myopic eye continues to change its refraction for a long time.

Therefore the separability of M from the other refractions seemed to be unquestionable. It is easy to understand that the search for exogenous causes did not cease, and that these causes were believed to be found again and again in near work.

The formation of the refraction is undoubtedly connected with the growth of the eye. The eyeball of the newborn has an average length of 17 mm. and a capacity of 2·2 c.cm.; that of an adult is 22·5 mm. and 6·5 c.cm. It sounds strange, but we know almost nothing about the course and details of this enormous increase. Seefelder, an expert on the development of the eye, says our knowledge about the extra-uterine growth of the eye is very deficient and needs urgent completion.

About the refraction itself we know only that the newborn has an average H of 2·4 dioptres; this decreases to 1·8 D. till the third, and to 1·5 D. till the sixth year of life (Hartman, Herrnheiser, Steiger).

In the sixth year the axis of the eye has already reached the adult average. If the refractive power remained unchanged during this time, there ought to have been an average M of 14·1 dioptres.

It was Best, Wibout, Berg and others who occupied themselves with the correlations preventing this disarrangement. It was found, as it can be foreseen, that there is a positive correlation between refractive power and axis and a negative one between corneal and lenticular focal distances, but nothing was said about the substance of it.

Although it is difficult to find an explanation for a graduated correlation, it has evidently much to do with the growing of the eye. In order to maintain the right proportion between axis and focal distance during the lengthening of the axis, the refractive power has to decrease. The increase of every spherical surface is necessarily connected with an increase of the radius and therefore

with a lessening of the refractive power. The main rôle in this process must be played by the lens; its refractive power has to decrease greatly, at least 13-14 dioptres.

Any discordance in the correlation during the formation of the eye must lead to ametropia. Thus the definitive refraction must depend also on the time when growth finished, depending, of course, upon the starting values.

About the decrease of the refractive power as a consequence of growth we are not well informed, yet it seems to be finished in the 5th-6th year of life. There are two components, cornea and lens.

A decrease of the refractive power of the cornea is, as far as I know, not observed; on the contrary, if there is a noticeable change, it is an increase in the optical zone. Hence it is the lens that carries the burden of compensation. Unfortunately, the refractive power of the lens is not measurable by clinical methods. We know only that there is a gradual slowing down of production of lens fibres, compensated by a progressive sclerosis, and both are continuous during life. We have no means of expressing this process in numbers.

About the axis of the eye we are not much better informed. We know that its length varies between 20-30 mm.; it reaches even 32-34 mm. in extreme cases. In the majority of cases its growth ceases at the end of the 5th year, but in a considerable number it grows further, in some cases till the 23rd-24th year of life.

This is not very much, yet enough to supplement Steiger's doctrine about stabilisation, and to explain the formation of the refraction as follows: The two optical factors, refractive power and axis, are changing as long as their anatomical substrata are in growing. As soon as both factors come to a standstill, the refraction is stabilised. Thus the final refraction of the eye is determined:

(1) By the combination of the inherited optical elements.

(2) By the process of stabilisation, also inherited but independently of the optical elements.

(3) By the correlation, this being in actual fact nothing else than the relation between the two first factors.

From the standpoint of stabilisation one can attribute to every eye a " biological value " that is independent of its refraction. On this basis all eyes may be classified into three groups:

(1) Eyes of reduced biological value; the stabilisation takes place before the complete perfection of the refraction.

(2) Eyes of full biological value; the stabilisation occurs together with the harmonic perfection of the eye.

(3) Eyes of surpassed biological value; the stabilisation is late, the eye is overgrowing its harmonic measures.

I might lay stress upon the important fact that theoretically every refraction is possible in every group. A hypermetropic or myopic eye is of full biological value if it is in every respect normally developed, and its ametropia is only caused by the chance combination of the optical elements. On the other hand, an emmetropic eye may be of reduced or surpassed biological value if the E is the consequence of stabilisation at a wrong time. Supposing, for example, the combination should have resulted in a H of 6 dioptres, yet stabilisation of the axis was late, the axis became therefore 2 mm. longer. The result is E, though the eye is of surpassed biological value and in its structure myopic.

Between the biological value and the time of the stabilisation there seems to be the following connection:

(1) Eyes stabilised at the end of the second year of life are of reduced biological value.

(2) Eyes stabilised at the end of the first decade are of normal biological value.

(3) Eyes that are stabilising in the 'teens are of surpassed biological value; their stabilisation may sometimes reach as far as the third decade.

The passages being continuous, the set limits are arbitrary, but they correspond well enough with the average clinical observation.

The refraction of the new-born being hypermetropic, the eyes of the first group remain in the majority hypermetropic, and those of the second, emmetropic. The clinical manifestation of the third group is necessarily myopia; it is thus easy to understand that myopia can generally appear only in the second decade, and has a progressive character—this meaning, in our view, retarded stabilisation.

The correctness of our statements could be proved only by ample material for observation, such as, for example, the observation of 1,000 eyes, each followed individually from birth till adult age, with a continuous record of the clinically measurable data: corneal and total refraction, corneal diameter, and axis. Unfortunately, there is no possibility of measuring the lens and axis. All the many mass-examinations we have at our disposal at present are only fixed cross-sections of a population. They can be treated from various statistical points of view, but they give a very uncertain insight into the happenings and changes of the individual eye.

It would be most important to find an increasing and decreasing H as well as decreasing M. It is only increasing M

that we are, to a certain degree, acquainted with. Blegvad published a remarkable paper about 64 cases of myopia observed during a long progressive period. I published some smaller material, comprising 15 cases. In both statistics there are cases when the M was stationary from early childhood: they could be explained as eyes of normal biological value, showing M of combination.

There is one definite conclusion we can draw from these tables: the majority of these eyes stabilised in the second decade.

About decreasing H we know almost nothing, though its existence is very probable. There are the cases of convergent squint which "cease" later. Such cases can be explained only by a decreasing H, when a facultative H turns into a relative one in time, that is, still at a young age, when the convergence is not yet static but dynamic. We would say that, in our view, these cases are hypermetropic refractions of slightly prolonged stabilisation. And rarely do we find in these cases E, and exceptionally even low degrees of M.

But this is only deduction and not observation. I was, and I am, continually searching after decreasing H, but up to the present time I have not found any case where I could have stated with certainty that a decrease of the refraction had occurred. Of course, this rarity can be explained by the probable assumption that hypermetropic eyes are generally very nearly stabilised in the first years of life.

Of the greatest significance, from our point of view, is the increasing H and the decreasing M (naturally with the exception of senility and disease). Such cases must be extremely rare, as we suppose that in such cases, contrary to the general rule, the axis is already fixed while the refractive power is still diminishing. Only chance could produce such a case, or very extensive mass-observations extending over many years. It was Doppel who mentioned, in the Medical Society of Vienna in 1942, eighteen cases of increasing H found in the squint-material of Lindner's clinic. His explanation was that atropine does not produce full paralysis of accommodation in children always. Lindner, who took part in the discussion, suggested a change in the refractive power.

The two deviations of the refractive curve of the adult age, the excess and the asymmetry, have been often quoted against the hereditary interpretation of myopia. By adding stabilisation to Steiger's doctrine, they seem to be explicable without giving up the hereditary basis.

It is known that the refractive curve of the new-born is a regular binomial curve, whereas that of the adult shows an

accumulation at E and a lengthening of the myopic side (Fig. 1).

Although we are far from being exactly informed about the details of stabilisation, we may assume that after birth all eyes are still growing (except the rare cases of microphthalmos). In the first 6 years about 60 per cent. are stabilised, in the following 4 years an additional 20 per cent., and the rest up to the 24th year (Fig. 2). The curve of stabilisation shows a turning point around the 6th year, with a maximum of the second differential quotient.

If we try to draw another curve, that is, showing the percentage of eyes attaining E in the marked year (of course, again only by rough estimation), we obtain a very asymmetric curve that shows a very marked maximum again around the 6th year (Fig. 3).

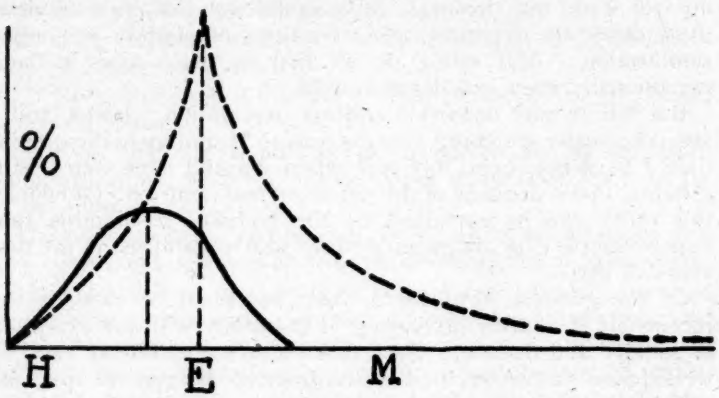

FIG. 1.

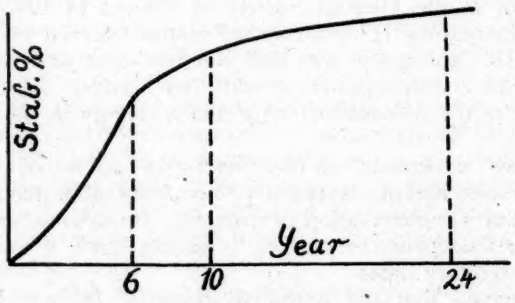

FIG. 2.

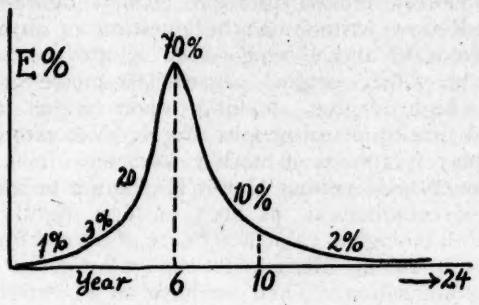

FIG. 3.

Collating the two curves, we see that the maximum of emmetropised cases coincides with the maximum of stabilised cases around the 6th year of life. Out of this summation an excess of emmetropia must necessarily arise. In other words, most eyes are wandering in the first decade of life from H through E towards M, but are in the majority of the cases stopped at emmetropia by the stabilisation.

From the curves the explanation of the asymmetry is apparent. At a rough guess we have to put the eyes of retarded stabilisation at 20 per cent. These are wandering from the left side of the binomial curve of the new-born gradually to the myopic side, and further, the later the stabilisation is taking place. On the left side there is a decrease, on the right side a corresponding increase, both in thickness and length.

The stabilisation being inherited too, in this interpretation the excess and asymmetry are a constituent part of the refractive curve, and typical for a given population.

The problem of stabilisation is closely connected with the general problems of growth. We know the organs and tissues of the body are subjected to very different rules of growth. For example, the central nervous system is far ahead of muscles and bones. The inner ear is already fully developed at birth.

Organs composed of various tissues must have their own particular rules of growing. The eye has, on the one hand, tissues of ectodermic origin, with rapid growth and quick development; on the other hand, tissues of mesodermic origin, with generally a very long period of growth. In the reciprocal influence they exert on each other the secret of the correlation is hidden. Primary importance must be given to the two interdependent but heterogeneous tissues, the retina and the sclera—a problem that has been already reviewed by Vogt.

Another closely related problem is that of the "extreme variant." Recent writers on the question of myopia—Tron, Scherer, Kronfeld and Devney—even if they are inclined to accept its hereditary origin, nevertheless make an exception of M of high degree, looking upon it as a common pathological process of exogenous origin. Yet extreme variants always display symptoms of morbid character. It is true a high degree of ametropia—neither M nor H—cannot be interpreted as a variant of combination, as such an eye, rightly stabilised, must be of full biological value and hence of normal function. But there seems to be no obstacle to explaining it as an extreme variant of stabilisation. Then we have as an extreme limit on the left side microphthalmos (theoretically even anophthalmos), and on the right side the highest degrees of M, both extremes showing various symptoms of degenerative and pathological character.

It is more than 10 years that I have been trying to find some practical consequences of the "doctrine of stabilisation," and to follow the fate of myopic patients from this point of view.

The parents of a child with beginning myopia are primarily interested in the prognosis. And really this is perhaps the most important practical question. To give an answer I try first to get some information upon the stabilisation of the parents and the antecedents. Then the construction of the eye itself gives some indication. Low corneal refraction (38-40 dioptres) is worse than higher values. A myopic (or even emmetropic) refraction of a child with a low corneal refraction may be already the sign of undue length of the axis, thus of a retarded stabilisation. The similar significance of the myopic conus and of the myopic fundus has been well known for a long time.

The recording of the yearly changes also gives indications. Although there are cases with periodic changes of increase and stability, the general rule is continually decreasing progression till the 20th year, and so we are able to foretell the definitive refraction approximately. Thus one commonly finds sufficient indications to judge whether the eye is already stabilised or nearly so, or is going to be an extreme variant.

In my opinion, with this judgment, and the reassurance of parents (and, of course, prescribing spectacles), the duty of the eye surgeon is fully completed; and should the case ever become an extreme variant, for the present we cannot do any more. The inherited duration of the stabilisation cannot be stopped by any means, least of all by restriction of near work. It is true the question of the origin of refraction and of the causes of myopia are far from being cleared up. Steiger's doctrine, as well as my

statements on stabilisation, are, in their uncertainty and unproved state, very open to attack. But still more so is the case with the opposite doctrine of the "school myopia." It is not only unproved, but one can bring weighty facts against it; as an example I refer to research on twins. There is, therefore, much to be said for the view that consequences of practical importance should not follow the doctrine of the school myopia, and restrictions in the near work of the young myopic patient should not be made.

Summary

Steiger's doctrine of the origin of refraction is enlarged with the conception of stabilisation.

Stabilisation is the cessation of the growing of the eye; its term varies with individuals. It plays a rôle equal to the combination and variation of the optical elements in the formation of the definitive refraction, and it is equally an inherited quality. The cause of the higher degrees of myopia is interpreted as retarded stabilisation.

The two weak points of Steiger's doctrine, the excess and the asymmetry of the variation-curve, are explained by the biological peculiarities of stabilisation.

A detailed knowledge of stabilisation will enable us to foretell the future of an early myopia.

Near work has nothing to do with the development of individual myopia, therefore restrictions in reading and studying by the young myopic patient should be put aside.

PIGMENT-ANOMALOSCOPY: A NEW PROCEDURE FOR TESTING THE COLOUR-SENSE*

BY

Professor A. KETTESY

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As is known there has been up to now one method that enabled us not only to test but to measure the colour-sense in some degree: the mixing of spectral lights, as realised practically in Nagel's anomaloscope. Theory and knowledge of colour-sense and colour-blindness have been exclusively based on results obtained in this way.

The colours we see and discriminate throughout life differ from spectral lights; in opposition to the latter we call these "pigment-colours."

The important physical difference between the two forms is

* Received for publication November, 1947.

well known: the spectral-colour has one wave-length or is built up at most of a very short section of the spectrum. The pigment-colour on the other hand includes all wave-lengths of the half of the colour-circle, thus being sometimes more than the half of the spectrum (*W. Ostwald's* doctrine of the "*colour-half*").

It is less well known that the physical difference becomes sometimes manifest in the sensual perception also. These are, for example, the rules of colour-mixing, with considerable divergence between spectral and pigment colours. From our standpoint there is the important fact that persons with defective colour-vision react differently sometimes, depending on whether the colours are spectral lights or pigments (Nagel, Rosmanit, Köllner). In practice it is not a rare occurrence that a deuteranomalous person makes mistakes with Nagel's anomaloscope and not with the pseudoisochromatic tables; or that a protanomalous sets a normal or almost normal Rayleigh-equation, and shows on the other hand great irresolution in the pigment-tests. It was because of this that some authors would have banished the anomaloscope from the current testing methods of colour-vision as misleading.

The question is far from being cleared up. To get some insight into the problem, the first task would be to construct an instrument by which we would be able to mix measured pigment-colours as we do with Nagel's anomaloscope.

The production of such an instrument is possible since W. Ostwald has succeeded in building up his colour-body, representing in it all pigment-colours well defined and exactly measurable. Though the polemics about the scientific value of the colour-body have not been settled definitely, its great practical value is beyond question. To the ophthalmologist who tests colour vision it is a help, and in the future it will probably enable us to penetrate more deeply into some of the unsolved questions of the colour-sense.

We have only to produce an instrument that mixes defined and measured pigment-colours additively and allows these two mixtures to be compared simultaneously, as is done in Nagel's anomaloscope with spectral colours.

The rotating disc, this well-known expedient of additive mixing, is not applicable for our purposes. Instead, we have to take cylinders which, rotating around their axes, mix the colours of their surfaces as well as the disc. This has been done. We took two parallel cylinders side by side, that could be pushed independently of each other to and fro during rotation. There were some technical details to solve, but we had at last the necessary construction, the "pigment-anomaloscope," fully coming up to our expectations. It proved shortly to be a useful and readily applicable instrument for testing and studying colour-vision.

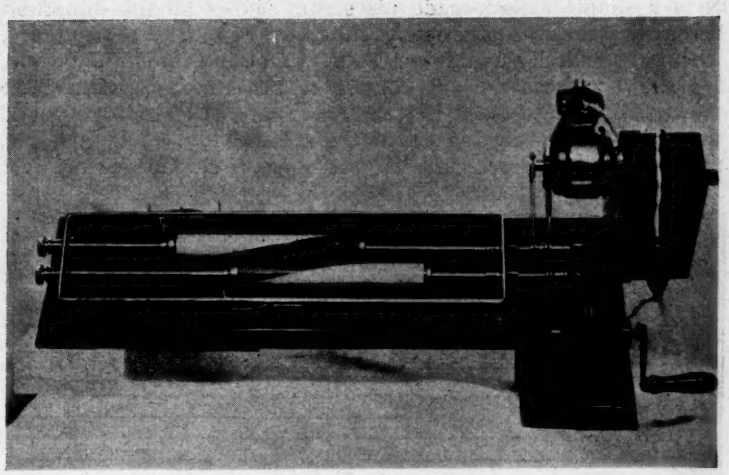

FIG. 1.

The pigment-anomaloscope uncovered.

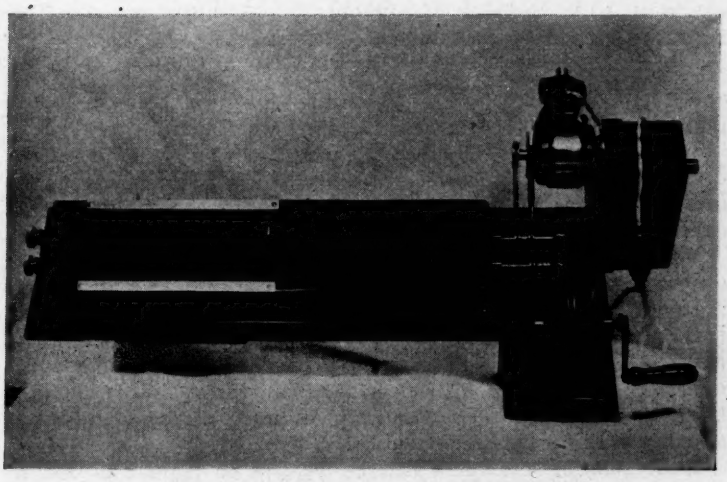

FIG. 2.

Pigment-anomaloscope covered, showing the observation slit.

The model we have been using is reproduced in Figs. 1 and 2. It is a simple artisan-made piece, but shows all the important features. It works alternately either by hand or by electricity. The two cylinders glide on steel axes and are changeable. On their surfaces are the colours to be mixed, on detachable papers. These are, of course, carefully selected and determined according to Ostwald's colour-body. For example, there are "*8 na*" red and "*20 na*" green on the one cylinder

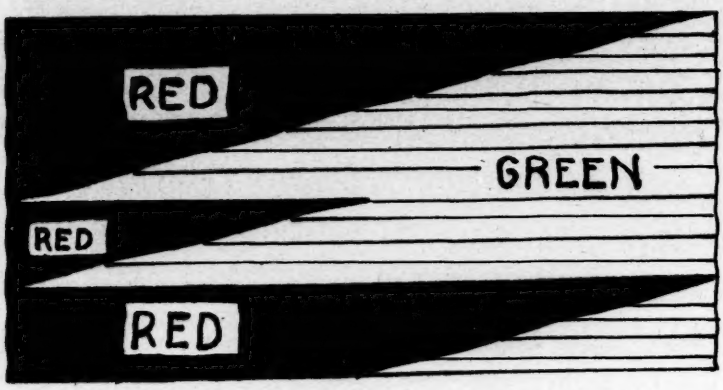

FIG. 3.

The surface of the cylinder with the two colours to be mixed, showing simultaneously the middle.

and "*a*" white and "*p*" black on the other, this being the basic pigment-mixture of red-green, matched with neutral grey.

The surface of the cylinder is a parallelogram, it is diagonally divided for the two colours. In order to get a more perfect mixture the surface can be sub-divided into narrower parallelograms (Fig. 3).

We see on the left end of the lower rotating cylinder pure red, on the right end pure green. Towards the middle both colours are getting more and more greyish, till in the middle they meet in a small stripe of neutral grey. On the upper cylinder there is a continuous change of grey from black to white. Both cylinders are covered with a black metal plate with a linear slit in it (Fig. 2). The examinee sees only as much of the cylinders as appears in this stenopæic opening.

Both rotating cylinders can be pushed to right and left by handles. Simultaneously with the two handles there are two indicators moving on tape-measures, showing the position of each cylinder. The zero indicates that the middle of the cylinders are in the slit.

When the apparatus is in gear, the examinee has nothing else to do but to push both cylinders to right and left till he sees in the slit above as well as below the same colour, neutral grey. In this position the indicator of the lower cylinder shows the amount of red and green necessary to obtain the match. In a normal trichromatic case this is fifty-fifty, the indicator should point to zero, or be very near to it. That adjustment corresponds fully with the normal Rayleigh equation.

The protanomalous requires more red, the deuteranomalous more green. In matching, the indicator stands somewhere on the right or left side of the tape-measure, showing the necessary amount of the colours. To make a record we have only to note the side of the tape-measure (f.i. D or P), and the figure at which the indicator points. For example, "*D 34*" indicates that the examinee found equality on the green side of the cylinder, 34 mm. from the centre, hence took 67 per cent. green and 33 per cent. red instead of 50-50 of the normal.

To register the grey cylinder is commonly superfluous, as it has only a theoretical value. We use it in practice only to give the examinee a grey to be matched.

There is a parallel between the recording of our instrument and Nagel's anomaloscope. The zero of the latter (that is the equation of the normal) is usually between 50 and 60 (mostly at 54). Higher figures denote protanomaly, lower ones deuteranomaly. We could as well put zero in the place of 54, in which case the records of both anomaloscopes might obtain the same meaning (except the fundamental difference). On that account Nagel's anomaloscope is well replaced by our instrument.

But it is more than a simple supplement, as it completes Nagel's anomaloscope in many respects. These are some of them:

(1) The cylinders being changeable, all imaginable mixtures are easily effected. Out of these the yellow-blue mixture has a practical value in two directions: it is a test for exposing simulation, and we might find by its help the rare condition of tritanomaly.

(2) Comparing the results obtained on both anomaloscopes, we are able to get some insight into the question of the difference between the perception of the same colour whether of the spectral or of pigment variety. The direct comparison of the results has been made possible by the well-known quotient of v. Kries (Q), deducted from the relation

$$Q = \frac{\text{green}}{\text{red}}\,(\text{normal}) : \frac{\text{green}}{\text{red}}\,(\text{examinee}),$$

green and red meaning the amount of colours in per cent. used to obtain neutral grey.

The examinee being normal, the Q has to be necessarily 1. In the very same manner the Q of a protanope has to be more, of a deuteranope less than 1. The great value of the quotient consists in eliminating all differences that arise out of the differently constructed and adjusted types of anomaloscopes. Thus the quotient gives a generally valid character of a person's red-green perception. If there were a discordance between the spectral and pigment quotient of the same person, an explanation could be found only in a difference between the perception of the spectral light and pigment colour. We found such cases sometimes in our investigations. There is, for example, the analysis of the following case:

On Nagel's anomaloscope a deuteranomalous examinee sets the equation at 30. The drum of our anomaloscope is divided into 88 lines. The normal equation is at 54, hence the first fraction of v. Kries' quotient is 34/54. The fraction of the examinee being 58/30, the spectral quotient is found to be 0·32.

The cylinder of the pigment-anomaloscope has a length of 200 mm. and a circumference of 100 mm. The zero being in the middle, the normal equation is 50/50. At 100 mm. it is from 50 to 100 per cent. of colour, we obtain the numerator of the division by adding to 50 half the number set by the examinee. The number completing this sum to 100 is the denominator.

The same deuteranomalous patient found neutral grey on the pigment-anomaloscope at D 32, hence the division of the quotient is 66/34. The quotient itself is 0·51.

We see there is a difference of 0·19 between the spectral and the pigment quotient. We may conclude that the perception of green has been 19 per cent. better when presented in pigment form. The examinee passed the pseudo-isochromatic tests faultlessly. This fact seems to confirm our conclusion.

(3) The pigment-anomaloscope is well applied to determine the threshold of the colour-stimulus—a new possibility. In practice there did not exist such a method. It has not only theoretical interest but it makes a welcome completion of the colour-sense tests.

We have only to put the colour on to the cylinder in the shape of a triangle, the two supplementary colours on the two ends of the cylinder, and interpolate white triangles (Fig. 4), the latter serving to eliminate the disturbing influence of the light-sense.

The examinee has to find the inner borders of the coloured impression. Starting from the middle, he sees only a change into grey in the beginning. He stops as soon as he has recognized a coloured impression. Of course, we do not obtain an absolute value, but in equal circumstances a comparable value.

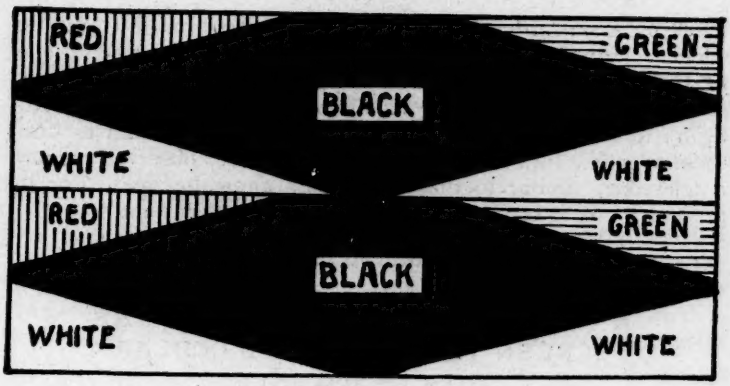

FIG 4.
Arrangement of the colours for threshold examination.

Anomalous trichromats always display such an increase of the threshold that it alone is sufficient to reveal their anomaly. We find generally an increase on both sides, yet protanomaly shows a greater increase in red, deuteranomaly in green, following the theory of Young-Helmholtz.

With the aid of threshold-investigations perhaps we shall be able to penetrate deeper into some hitherto obscure problems of the colour-sense. There is, for example, the question of Wölflin's " relative red- and relative green-sightedness," also the normal varieties type I and type II of Tschermak-Seysenegg, all probably associated with threshold differences.

There are the rare but interesting cases of colour-weakness with a normal equation (Edridge-Green). In such cases we could suppose an equally increased threshold for both complementary colours; of course, investigations in this direction are still lacking.

(4) Finally it may be mentioned that we are able to reproduce every continuous colour-band in a simple way on the pigment-anomaloscope, and also the spectrum. Naturally they are composed only of " colour-halves," nevertheless they show every peculiarity of the original in the sensual perception and are therefore applicable.

Conclusion

I have tried to show that the pigment-anomaloscope would make a useful completion of colour-testing. It could even enlarge our knowledge of colour-vision. The model reproduced in Figs. 1 and 2 is, of course, in many respects rough;

made by a skilful mechanic it could take the form of a faultless, silently running and exact instrument. It could even be further improved for scientific purposes. It would be necessary, for example, to make its illumination independent of daylight; to narrow the field of observation to points and to bring them together into one round divided surface, observed through a telescope, similar to that of Nagel's anomaloscope. For the present I had to content myself with the model at hand.

A NEW METHOD OF APPLYING THE SCREEN TEST FOR INTER-OCULAR MUSCLE BALANCE

BY

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ASSISTANT REGISTRAR, MANCHESTER ROYAL EYE HOSPITAL

THE apparatus described in this communication was developed at the Manchester Royal Eye Hospital as the result of a series of experiments designed to overcome certain difficulties experienced in the application of the Hess screen test.

In the Hess method, a colour separation system is used to obtain dissociation of binocular vision, and the difficulties experienced were all attributed to this. Such a system, whilst theoretically capable of perfect results, is apt to be inefficient in practice, because of the difficulty of manufacturing materials of the exact and stable colours required for the screen, pointer, and goggles. Even if initially correct, these are likely to deteriorate with age and use. If the colours of the components used are not exactly correct, the dissociation obtained is only of relative degree, and errors then are liable to occur in the test. Thus the red pattern of the screen may be faintly visible through the green glass, or the green pointer through the red glass. The resultant accuracy of the test depends on the brightness of these images compared to the correct ones.

If the secondary image allows of uniocular localization of the pointer to the cardinal points through either glass, the test is rendered useless; or even if the position of the green pointer is seen through the green glass, and related, as it should be, to the apparent position of the red cardinal points seen through the red glass, still the result may be inaccurate, owing to the fusional stimulus caused by the screen pattern being visible, to a greater

or lesser degree, to each eye, for this distorts the possible angle of deviation.

Even when colour separation is perfect, errors may still occur, for a keen observer may be able to effect monocular localization of the pointer to the cardinal points if he notices the eclipse of the red screen-pattern which takes place as the pointer is moved over its surface.

Many patients have trouble with the test for yet another reason, as they fail to recognize the pattern of the screen, or the position of the pointer, because of the low level of contrast present, when these are seen against the black background of the screen through red-green goggles. As a result, they cannot appreciate what is required of them to complete the test. This inability is partly due in a small proportion of cases to some defect of red-green vision in the patient under test.

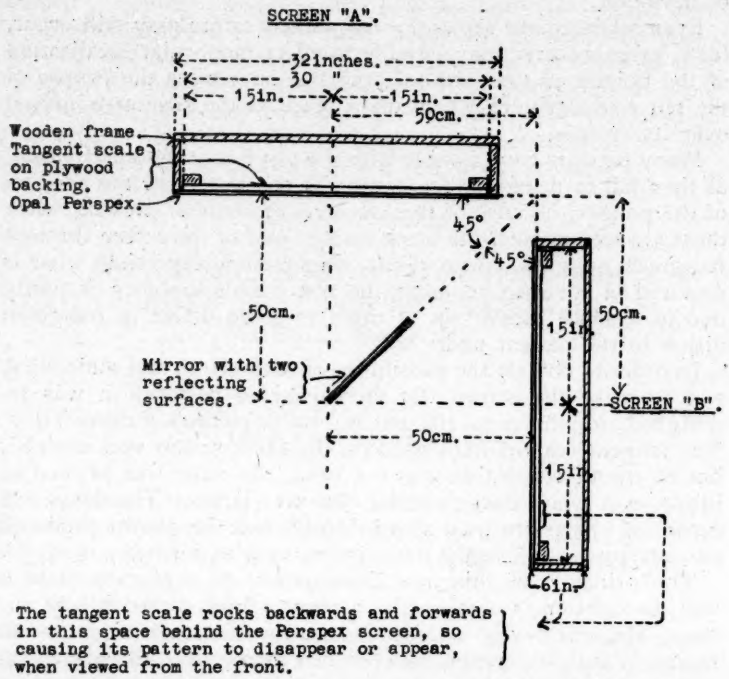
In order to obviate the possibility of such errors and difficulties, and to make the screen test more easy to perform, it was redesigned around a more efficient and stable method of dissociation. The tangent scale pattern used on the Hess screen was retained, but as colour separation was not used, the scale was printed in black on a white background to ensure clarity. The Hess test recording charts are used as previously, and the graphs produced are interpreted in exactly the same manner as before.

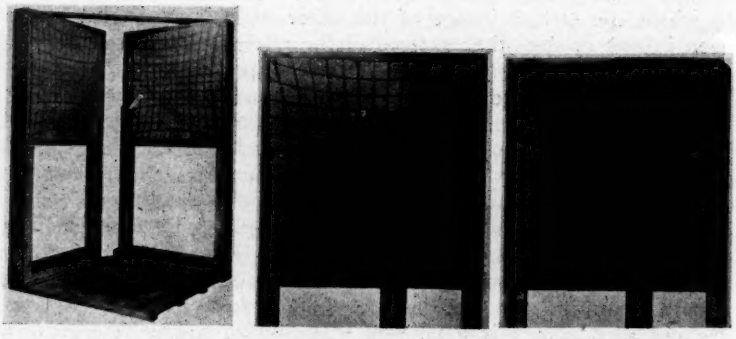
The principle of this new development of the screen test is that dissociation is obtained by a plane mirror placed before one eye. The mirror has a reflecting surface on each side, and is placed in such a position between two identically printed tangent scales erected at right-angles to each other, that a symmetrical system is formed, in which each scale is situated at the position to which the virtual image of the other scale is projected, when seen in one or the other surface of the mirror. Thus the patient sees different but identical scales exactly superimposed. To avoid fusional stimulus and afford a blank surface before the plotting eye, each scale is so constructed that its pattern may be made to appear or disappear as required during the test.

Reference to the illustrations will amplify the following description of the construction and use of the apparatus.

Two tangent screens are used, each being a composite assembly of a plotting screen and tangent scale. Each plotting screen consists of a sheet of light opal perspex, 32 in. square x $\frac{1}{8}$ in., mounted on the top half of a wooden stand, 64 in. in height. Behind each screen is a tangent scale, 30 in. square, the pattern of which is exactly as is used on the Hess screen, that is, one having a working distance of 50 cm. It is, however, marked in black lines on a white background. The tangent scale is sup-

PLAN OF MIRROR SCREEN TEST





(Photographs by courtesy of the Department of Medical Photography, Manchester Royal Infirmary)

General view of apparatus. Screen "A" on the left. Screen "B" on the right.

Screen "A" with virtual image of screen "B" seen superimposed in the mirror.

Screen "A" with tangent pattern suppressed ready for plotting projection of left eye. The right eye fixing the mirror image.

ported by a plywood back-board held on two wooden struts, which hinge on to the bottom of the frame holding the plotting screen. The tangent scale is thereby enabled to rock backwards and forwards behind the plotting screen, so as to be either in contact with it, when its pattern shows clearly through the opal perspex, or separated from it by a distance of about 4 in., when its pattern is so diffused as to be invisible.

The two tangent screen assemblies are secured in relation to each other on a firm baseboard, being also braced by a top strut. Their position is such that the two plotting screens are vertical and at right-angles to one another, and so that with both tangent patterns made visible, the centre horizontal lines of the scales are each at the same height from the base, and the centre vertical lines each parallel to, and 50 cm. distant from, the plane of the other screen. These adjustments must be accurately carried out, as upon them and the position of the mirror, rest the exact alignment required for the success of the test.

The mirror is made from two $\frac{1}{8}$ in. thick sheets of plate-glass, each 12 in. square, silvered on the rear surface and cemented together back to back so as to give a reflecting surface on each side. This mirror is mounted on a rigid steel stand equipped with screwed bolts in the base, whereby the position of the mirror can be adjusted.

The mirror on its stand is placed in position between the plotting screens, so that its reflecting surfaces lie in the plane which bisects the angle between them—that is, at angle of 45 degrees to either screen. The front edge of the mirror must be on a line 50 cm. distant on perpendiculars drawn from the centre verticals of either tangent screen. The height of the mirror should be such that the line bisecting it horizontally is level with the centre horizontals of the tangent screens.

The accuracy of the alignments carried out may now be checked by viewing each screen, and the part of the other screen as seen in the mirror, from a distance of about 6 ft., when the lines of the virtual image should be continuous with those of the screen on which it is superimposed. If this is found to be correct the apparatus may be considered ready for use.

Two pointers are used in the test, each consisting of a metal rod about 50 cm. long. The one used by the patient has a ring at its tip after the style of the Law pointer often used in the Hess test. The one used by the operator has a small disc at its tip half the diameter of the ring on the other.

The patient sits close to the mirror, with his nose touching its front edge. He faces screen "A" if the projection of his left eye is to be tested, or screen "B" if his right is to be tested.

The charts obtained by plotting from these positions correspond to those obtained by the Hess method when wearing the green glass before the left and right eyes respectively.

Suppose the patient to be facing screen "A." His right vision is intercepted by the mirror, in which he sees screen "B" projected forwards as a virtual image, to appear as if superimposed upon screen "A." The patient's left eye, its vision unobstructed by the mirror, sees screen "A" directly, but cannot see screen "B" as this is situated laterally. Nor can the right eye see screen "A" because of the mirror. Binocular vision is, therefore, completely dissociated, but similar tangent scales are exactly superimposed by the symmetry of the apparatus.

The tangent pattern of screen "A" is now suppressed, leaving a blank surface before the patient's left eye. The tangent pattern of screen "B" still remains visible to the patient's right eye, appearing as a virtual image projected on to the blank surface of "A." The operator now indicates on screen "B" the cardinal points which he desires the patient to fix, by holding the disc at the tip of his pointer over each position in turn. Small oscillatory movements are made with the disc over the cardinal point, so as to stimulate more exact foveal fixation by the patient, who observes the virtual image of the disc through the mirror. These movements also help to eliminate alternating macular suppression, which sometimes causes trouble during the test. The patient holds the ring-tipped pointer in his left hand and with it encircles the apparent position of the disc. As the ring is seen only by his left eye against the blank screen "A," it indicates the foveal projection by this eye of the image of the disc seen by his right eye, depending upon the cerebral relation of the two foveal pathways, and the interocular muscle balance. The position of the ring is now measured by momentarily causing the re-appearance of the tangent pattern on screen "A."

The cardinal points required to complete the square pattern covering the ocular muscle actions are now plotted in sequence. The measurements taken are entered on the left-hand side of the diagnosis chart, exactly as plotted by the patient on screen "A."

It will be realized that the patient sees the virtual tangent scale reversed by the mirror in the horizontal meridian, but as the nine cardinal points are symmetrically situated about the centre line, the phenomenon of image reversal need not be taken into account when all nine points are plotted in sequence. Only if a single point is under consideration during plotting need this reversal effect be remembered.

To test the right projection, the patient must change his position so as to face screen "B." This time he fixes the cardinal

points indicated on screen "A" with his left eye, which now confronts the other reflecting surface of the mirror. The projections of the visual axis of the right eye corresponding to the various points fixed by the left, are now indicated by the patient, who this time holds his pointer in his right hand and guides it by the vision of his right eye over screen "B." During this half of the test the tangent pattern of screen "B" is suppressed during plotting.

The measurements taken are transferred to the right-hand side of the diagnosis chart, which on completion is interpreted in exactly the same manner as is a record of the test done by the red-green dissociation technique of Hess.

The method of construction described above is not the only one applicable to the screen test by mirror dissociation, but was one adopted for the sake of convenience and according to the workshop facilities at our disposal.

Possibly a better method of superimposing the tangent patterns on to the plotting screen is a rear-projection system, in which the image of a tangent scale printed on a transparent base, is thrown on to an opal screen by back-lighting. By this means control of the pattern is obtained through an electric switch. Messrs. Theodore Hamblin, Ltd., of Wigmore Street, London, are conducting experiments on this system with a view to production of the apparatus.

Another way is to employ symmetrically mounted cork or such-like screens, on which the plotting of the patient's projection is mapped by pins. The cardinal points for fixation are shown by a transparent tangent scale, which, on removal to the mirror image position, is also used to measure the position of the plotting pins.

Other variations, such as an automatic recording system, by which the projection is transferred directly to the graph-paper, are possibilities which have not yet been tried.

Whichever method is adopted, it will be realized that, as the apparatus requires to be installed as a semi-permanent fixture, and as its manufacture is more exacting, the initial cost will far exceed that for the original Hess screen test. The advantages offered in rapid, accurate and trouble-free results far outweigh the initial difficulties and expense involved.

The apparatus has been in daily use at the hospital at Manchester for almost a year, and during this time many hundreds of patients have been tested upon it. Although many of these had previously failed to perform the Hess test, not one failed to perform the mirror dissociation method. Amongst the numbers tested were several small children, all of whom readily gave readings which could be interpreted with confidence in their accuracy.

THE OPENING OF THE INSTITUTE OF OPHTHALMOLOGY, LONDON

ON November 4th an event occurred which it is hoped will be of some significance in the development of British Ophthalmology — the formal opening of the Institute of Ophthalmology, a unit of the British Post-graduate Federation of the University of London.

London, of course, has been a centre of ophthalmological teaching for many years — indeed, since the founding of the School at Moorfields in 1810. For over a century it remained the principal focus of ophthalmological inspiration for the English-speaking world. As research grew more complicated, however, and demanded for its satisfaction not merely the routine of the clinic and the simple facilities of a pathological laboratory where the ophthalmoscope and the microscope were sufficient equipment, but, in addition, a host of specialists — physical, physiological, biochemical and immunological — each with his elaborate equipment and all working as a team, it became apparent that if London were to maintain its position as a centre of advancement and progress, a more co-ordinated and systematized organisation was necessary.

Some twenty years ago a move was made, largely under the inspiration of Sir John Parsons, to remedy this defect, but financial support was not forthcoming and loyalties and traditions acted as a break to radical changes. At the same time, in the years before the second World War, the development of the British Post-graduate Medical School was a harbinger of future events and it maintained a close interest with the Medical School at Moorfields.

After the war, the British Post-graduate Medical Federation was formed within the University of London and the Medical School at Moorfields was invited to join the Federation as an Institute of Ophthalmology. With a view to co-ordinating all that was best in London, Moorfields, the Central London Ophthalmic Hospital and, later, the Royal Westminster Ophthalmic Hospital, became amalgamated by an Act of Parliament. Such a combination gave scope for wide planning within the three units and it was decided that the building of the Central London Ophthalmic Hospital should be converted — not a very extensive reconstruction — into a research and teaching Institute, and that the other two hospitals should act as associated clinical units. The result, it is true, is not entirely satisfactory, for the partial divorce of lecture rooms, library, museum, routine and research laboratories from the clinical departments, is a considerable handicap. It is a handicap, however, that it is hoped to overcome as soon as the economic conditions of the country allow new medical buildings to be constructed on a large scale. In the meantime, in the spring of 1947 the practice of the Central London

Ophthalmic Hospital began to be transferred, reconstruction work was pushed ahead and by November 4th, 1948 sufficient of the building was ready to allow a formal inauguration ceremony to be held.

The new Institute comprises a building of six floors of which the basement is given over to a cafeteria, kitchen, students' sitting rooms and cloakrooms, technicians' rooms, workshops and store-rooms. On the ground floor are the administrative offices and a department for clinical teaching and research clinics. A small orthoptic department has been retained for research purposes. The first floor houses a large department for medical illustration, equipped and staffed for photography in all branches, including fundus photography, cinematography and fundus drawing, and also contains a suite of rooms for the more elaborate types of clinical research. On the floor above are the library and museum, built up from the material available from the three parent hospitals, offices for the British Journal of Ophthalmology and Ophthalmic Literature, and a lecture hall to hold 100. Laboratories for morbid histology, bacteriology and allergy occupy the major part of the third floor. The remainder of the building is occupied by twenty-three laboratories fitted up for research in physiological optics, physiology, electro-physiology, biochemistry and radiography, with appropriate technicians' rooms, operating theatre, five animal rooms and appropriate accessories. During the present session there are 126 post-graduate students from many countries of the world, and at the time of its opening the Institute has on its staff 15 full-time research workers.

The opening ceremony was held on the afternoon of November 4th under the Chairmanship of the Earl of Rothes — Chairman of the Committee of Management of the Institute — before an audience of representatives of the University and the British Postgraduate Medical Federation, the provincial and Scottish Universities, together with many of the past and present staff of the three hospitals and the Institute. Lord Rothes briefly outlined the history of the development of the Institute and suitably welcomed the three guest speakers Sir John Parsons, Professor Alan Woods and Professor Weve — representing British, American and European ophthalmology who also gave inaugural addresses.

Sir John Parsons spoke of the two functions of the Institute. So far as teaching was concerned, the reputation of the three associated hospitals was already high, and with the greater facilities now available, it should become still higher in the future. So far as research was concerned the Institute was indeed fortunate for it had on its staff the type of men who were able and willing to do research and it also had the support of the Medical Research Council. It was quite illusory to imagine that the procurement of a building and the provision of finance could of themselves produce

original work of value: the success of research depended on the work of men with a flair for it. At the same time, an Institute of this type should only be looked upon as the first step in the right direction: co-ordination with general medicine and surgery as well as with the fundamental physical sciences was a necessity and that means an intimacy with a general hospital and university laboratories which must be topographical as well as spiritual.

Professor Alan Woods expressed his pleasure in participating in the inaugural exercises which he thought marked a new epoch in the advance of British ophthalmology. He brought with him the good wishes of American ophthalmology and particularly the congratulations of the Johns Hopkins University School of Medicine. He spoke of the great part played by Great Britain in the development of ophthalmology, and pointed out that, while the problems of clinical diagnosis and therapy were ably dealt with in the past by the large independent or semi-independent eye hospitals of Europe and America, a new type of Institute such as the present was now necessary wherein to tackle the problems of the future. The obvious clinical problems had been dealt with; the advances of the future must be solved by the co-operation of specially trained ophthalmologists with fellow scientists in a host of other fields, ophthalmic research must be co-ordinated with modern medical investigation and must be an integral part of the life of a University carried out in fellowship with colleagues in other branches of medicine and science. In extending his good wishes for the future of the Institute, the construction of which at this time of stress and reconstruction was typical of British courage, he said that anything his own School of Medicine could do to assist would be only a small acknowledgement of the debt owed by America to British ophthalmology.

Professor Weve traced the history of the development of ophthalmology in Europe, how it started two centuries ago with the surgical renaissance in France under the inspiration of Daviel, migrated after the French Revolution to Austria, revived under the stimulus of Helmholtz and v. Graefe in Germany and Donders and Snellen in Holland, and later, particularly in its optical aspects, in Scandinavia. Throughout all this time the place of England was high. In the earlier days the genius of Newton and Young was continued in clinical ophthalmology by such men as Bowman and Mackenzie, and the torch has been carried down to our own day by such men as Parsons. The two wars which have devastated Europe have not been without their influence in this development, but it was a great day not only for British ophthalmology but for world ophthalmology, that despite the ravages of war, sufficient enterprise and courage had been at hand to start an Institute of this type.

After tea and a tour of the Institute, the Lecture Hall was filled for a delightful inaugural address by Professor Woods on "Experimental Studies on the Pathogenesis and Therapy of Ocular Tuberculosis"; this will be published in a future issue of this journal. In the evening an enjoyable dinner was held at Claridge's Hotel, at which Professors Weve and Woods proposed the toast of the Institute, and Sir Stewart Duke-Elder replied.

CORRESPONDENCE

APOLOGIA PRO VITA MEA

To the Editorial Committee of
THE BRITISH JOURNAL OF OPHTHALMOLOGY

DEAR SIRS,—On giving up the post of senior editor I wish to thank all my colleagues on the Editorial Board for their forbearance and the great kindness shown to me for so many years. And I should also like to thank those subscribers who have from time to time written me appreciative letters. To know that I had the good will of the fraternity has been a great help. It might be thought that an editor's life comes within Mr. Mantalini's definition "one demd horrid grind," but I have not found this to be the case and my journal years have been very happy ones indeed.

Sir William Osler once wrote something to the effect that it was wonderful how a bad boy may fool his fellows if he once gets to work. I believe my only editorial assets have been two in number: first, writing has always come easily to me, and in saying this I hope that I have not been unmindful of the dictum of Edward Fitzgerald, that "easy writing often makes for difficult reading": secondly, I was early in life introduced to good English literature. In connexion with my first point I recall one of my prep. school reports in which my essays in divinity were commended, the master adding "he has a good fund of English on which to draw." Perhaps any facilities I may have shown in the concoction of annotations may be traced to this early source. With regard to my second point, the same master who praised my English essays (the less said about my efforts in Latin the better) was wont to read aloud to those of us who cared to listen, and in this way introduced me to Pickwick and The Rose and the Ring. My father also used to read out to us in the holidays and he took me through most of the Waverley Novels. Scott, Dickens and Thackeray are good foundations in English literature. And a parson's son who has to attend church twice a

Sunday, clad as Hood clothed the Devil, that is to say in his Sunday best, must be a hopeless ass if he does not learn in time to appreciate the extraordinary beauty of much of the prose of the Book of Common Prayer.

It might be thought that with my early theological leanings I should have done better to enter the Church, especially as a family living was, and is, situated among the hills of South Shropshire. But I had the gravest doubts as to my ability ever to become what one of the bidding prayers calls a discreet Minister of God's word. I felt, too, that I could never fill the pulpit from which my maternal grandfather had thundered at the rude forefathers of the hamlet who slept in the box pews beneath. The Rectory was a mile from the church, high up on the hill side, facing due east, and bitterly cold in winter.

I have never regretted that I chose the medical rather than the clerical profession. My choice of medicine was fortuitous, and was due to the Gloucester smallpox epidemic of 1896. My home was nowhere near Gloucester, but my father decided that the household should be vaccinated. As I was being done, it suddenly struck me that it didn't seem to be particularly difficult, and that here was a career in which the fool of the family might make good. My enthusiasm, however, received a couple of shocks before I left school. The first came from a schoolfellow, himself the son of a doctor, who asked me what I was to do in after life, and when I said I hoped to be a doctor, replied "do you think you have enough brains to pass the examinations"? The second shock was delivered by my housemaster, who, when I asked him if he thought I could matriculate at the University of London, said "my dear boy, it's no use, you simply haven't the brains." I must confess that on my school record they were both abundantly right, and only hope that my subsequent career has done something to correct the verdict.

When I joined the staff of the British Journal of Ophthalmology I had already had some practice in correcting proofs with E. E. Henderson. I had my consulting room in his house during the time that he was editing the Ophthalmic Review. We neither of us had much practice, and he would occasionally give me a spare set of proofs to correct, and go through them with me afterwards. I owe him a great deal, for he taught me much. Among other things, I learned to beware of the split infinitive, sentences ending with prepositions and those starting with a past participle. Tautology, journalese and slang were all anathema to him.

As soon as I joined the Journal I found I could always take my difficulties to Sir John Parsons and be sure of getting sound advice. I must have made myself a proper nuisance to him, to use an East Anglian expression; but he never seemed to mind, and I soon felt

that if he were satisfied naught else mattered. We all know how much he has done for British Ophthalmology, but only the editorial staff know fully what he has been to the Journal.

I am proud of having worked with him for the Journal, and would like to express my gratitude to him for his exceeding great goodness to me over a period of more than forty years.

In saying goodbye, I wish the Journal many years of prosperity and usefulness, and hope that those who work under the new arrangements will enjoy it as much as I have done in the past.

Yours faithfully,

R. R. JAMES.

WOODBRIDGE.

To R. R. J.

To the Editorial Committee of

THE BRITISH JOURNAL OF OPHTHALMOLOGY

DEAR SIRS,—It is with very genuine admiration and honour mingled with sadness that I salute my Editorial Chief, Mr. Rutson James, as he passes to well-deserved retirement. Like many famous men and women in our island history he comes from a large family brought up in a country parsonage, and belongs to a generation nurtured in that age of character and grace during the reign of Queen Victoria. The stock from which he comes, the background of his childhood and his training at Winchester, where "Manners makyth man" combined to make him a perfect example of the English gentleman. His courtesy to me through more than 19 years of happy association with him on the staff of the British Journal of Ophthalmology, and indeed to everyone he has dealt with, has been constant, and his sense of duty and rightness of the highest order. At times I have felt that he has been too lenient in handling my editorial misdeeds and shortcomings on occasions when I deserved stern rebuke. True to his character he would always take the full blame, and endure the discomfort of mind that went with this, for any fault committed by a subordinate, and this, for a nature as acutely sensitive as his, is a tribute to his courage and loyalty.

In this changing world men of his calibre and integrity are becoming rarer in all walks of life, and so we appreciate and value them the more. I could not have had a better chief, a wiser counsellor to whom to appeal for advice, or a more loyal friend. I owe him an immense debt for all he has taught me from his wide experience in literary matters, for the enjoyment of his whimsical humour, and for his high example of truth and honesty in writing and in all his dealings.

Yours faithfully,

H. B. STALLARD.

81, HARLEY STREET,
W.1.

NOTES

The Ophthalmological Society of the United Kingdom. Annual Congress, 1949

THE Annual Congress of the Ophthalmological Society will be held at the Royal Society of Medicine, 1 Wimpole Street, London, W.1, on March 31, April 1 and 2, 1949.

The subject for discussion will be "Corneal Grafting," which will be opened by Dr. R. Townley Paton (New York), Professor A. Franceschetti (Geneva), Professor G. P. Sourdille (Nantes), and Mr. J. W. Tudor Thomas (Cardiff). Members who wish to take part in the subsequent discussion are advised to intimate their intention before the opening of the Congress. It is emphasized that no member may speak for more than ten minutes.

Members wishing to read papers are asked to send the titles to Mr. Bridgeman as soon as possible. Abstracts of papers, which will be circulated at the Congress and subsequently to the leading ophthalmological journals abroad, should be submitted *not later than January* 31, 1949.

The Friday afternoon will be devoted to pictorial demonstrations of subjects of special interest. Members who wish to contribute are asked to communicate with Mr. Bridgeman as soon as possible.

The Annual Dinner will be held on Thursday, March 31. It is hoped that it may be possible for members to bring guests.

On account of the difficulty in obtaining hotel accommodation in London, all members who will require it are advised to make their arrangements in good time.

Hon. Secretaries { T. KEITH LYLE.
G. J. O. BRIDGEMAN.

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Royal College of Surgeons of England. Ophthalmology Lectures

THE following lectures will be delivered at the College in Lincoln's Inn Fields, London, W.C.2:—*Tuesday, March 29, 1949*, Professor A. Franceschetti (Prof. of Ophthalmology, University of Geneva), Cataract Associated with Lesions of the Skin, at 5 p.m.; Professor G. B. Bietti (Prof. of Clinical Optics, Pavia University), Protein and Amino-Acid Deficiencies in Ophthalmology, at 6.15 p.m. *Wednesday, March 30, 1949*, Professor E. Hartmann, Psychosomatic Symptoms in Ophthalmology, at 5 p.m.; Professor H. J. M. Weve (Prof. of Ophthalmology, Rijksuniversiteit) (the subject to be announced later), at 6.15 p.m.

W. F. DAVIS,
Secretary,
Postgraduate Education Committee.